Crop Profile for Carrots in Wisconsin

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General Production Information

Wisconsin is the second leading producer of processing carrots, behind Washington state, in the United States. Wisconsin contributes 13% of the total processing carrot production in the US. About 4,000 acres of carrots are grown annually--producing an average of 80,000 tons per year (20 tons/A) for the period 1992-95. Wisconsin carrot production is valued at $67.10 per ton. Nearly all of the carrots grown in Wisconsin are processed however, some are grown for fresh market sale.

Production Regions

Seventy percent of the carrots grown in Wisconsin are grown on muck soils in the central and southeastern parts of the state with an additional 25% grown on sand in central Wisconsin and 5% grown on heavy soils in the east central part of the state.

Cultural Practices

Carrots are a cool-season vegetable and although the tops are tender, roots are not damaged by a mild frost. The optimum temperature for growth is between 60 and 70F. Planting or harvesting at extreme temperatures is undesirable and should be avoided if possible.

Carrots should be planted on a level seed bed that is not to rough or cloddy. There should be no physical obstruction to root development to a depth of two feet or more since a carrot root is easily misshapen if it comes into contact with any obstruction. To assure optimum root quality, carrots are grown on deep, friable, fertile soils with adequate drainage. Soils which compact easily or have a high water table at any time during the growing season are unsuitable because these conditions may result in the development of forked roots, thus reducing crop quality. Fields with known infestations of nematodes should be avoided for the same reason. In Wisconsin carrots are primarily grown on muck soils.

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In late-April through June, carrots are seeded in beds in rows 16 to 18 inches apart. Carrot seeds are small in comparison to other vegetable seeds, and emergence is slow and irregular. Because carrot seed is relatively slow to germinate, seeds should be treated with a fungicide to prevent damping off before emergence. Young seedlings are small, weak, and fragile and lack vigor until the first true leaves appear. For these reasons, planting techniques are extremely important. Faulty planting can easily lead to spotty stands and low yields. Early irrigation aids in stand establishment and is particularly important in the seedling stage. Carrots should not be under moisture stress at any time. Soil should be moistened to the rooting depth when irrigating. Similarly, carrots should not be over watered because excess soil moisture can cause root splitting or cracking and inhibits color development.

Most of Wisconsin carrot growers use barley, oats, and rye as a living mulch. The barley is planted with the crop, usually sown over the entire bed, as opposed to the carrots which are sown in rows. The barley is then killed with an herbicide once the carrots are up and past the danger stage of being wiped out by excessive winds.

Carrots are heavy feeders; therefore it is important to make sure that nutrient availability is sufficient to support the crop. Soil tests are done on a regular basis to determine the correct amount of lime and fertilizer that the crop needs. Organic soils should have a pH of at least 5.6, while mineral soils should have a pH of 6.6. If manure is used as fertilizer it should be well rotted because coarse manure can cause irregular roots and forking. If lime is needed to raise the pH, dolomitic limestone is recommended, especially on sandy soils. The crop should be carefully monitored for symptoms of nutrient deficiency, particularly micronutrients. Carrots need moderate amounts of the micronutrients manganese, boron and copper. Soil and plant analyses are used to determine whether these nutrients are present in sufficient amounts.

Early planted carrots are harvested from late July to September. Late crops are harvested in fall, often well into November. Particular care should be taken when harvesting and transporting carrots in hot weather since high temperatures predispose carrot roots to decay. Carrots for processing are harvested by machine and handled in bulk direct from the field to the processing plant.

Insect Pests

Aster leafhopper (*Macrosteles fascifrons*) is the most damaging pest of carrots because of its ability to transmit the phytoplasma that causes aster yellows. 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. The first migrants are primarily female. Large influxes may occur in early summer as local populations develop from eggs that overwinter on weed hosts in northern states. Eggs are laid under the epidermis of leaves of susceptible

hosts. The leafhoppers progress through five nymphal instars and require 20-30 days for development. There are normally 2-5 generations per year. Cold winter in the Ozark area and southern grain states can lead to a low vector populations and low yellows incidence in the northern states. Disease incidence is reduced in hot summers.

Both nymphs and adults feed by inserting piercing/sucking mouthparts onto the vascular tissue of the plant and extracting sap. Damage is caused indirectly by introduction of the aster yellows pathogen with the saliva into the plant's phloem tissue. General aster yellows symptoms are vein clearing, chlorosis, stunting and twisting of stems and leaves, and proliferation of leaves and adventitious roots. On carrots the chronological symptoms begin as yellowing and twisting of new foliage. Later there is a dense growth of adventitious chlorotic shoots. Older leaves become bronzed and break off easily. There is a proliferation of roots on infected plants and roots are unmarketable due to their bitter taste. Infection often predisposes the roots to various soft rots. Yield loss can result when plants are infected at an early stage of growth. Twenty-four to 30 days are required after an infective leafhopper inoculates the carrot before symptom expression occurs. The time for symptom expression is slightly less on seedlings and very susceptible cultivars.

Aphids are occasional pests of carrots grown in Wisconsin. A number of aphid species attack carrots, but the green peach aphid is most common. Bean aphids are also occasional pests on carrots. Green peach aphids overwinter as eggs on woody shrubs and move to their summer hosts by June, or migrate in on southerly winds. Populations continue to build throughout the summer, with females continuously giving birth to live young. A single generation can be completed in 10 days under ideal conditions. In fall, reproductive, winged forms are produced which migrate to winter hosts, mate and lay eggs. Heavy rains help dislodge aphids from the plant and during high humidity, fungus diseases may greatly reduce populations.

Infested plants may be stunted or wilted with chlorotic foliage. Aphids typically congregate on succulent new growth and cause curled or shriveled leaves. Black "dust-like" sooty mold may appear and grow on the honeydew excreted by the aphids. High aphid populations in carrot usually result only when frequent insecticide applications are made to control aster leafhopper.

Black cutworms (*Agrotis ipsilon*) are a sporadic pest of carrots in Wisconsin. They are most problematic in low, wet, grassy areas. The adult cutworms are gray moths which have a series of distinctive dark markings on their forewings and lighter colored hind wings. Black cutworm larvae generally feed at, or below the ground surface at night or on cloudy days and hide in the soil or under foliage during the day. The large, greasy, dark gray larvae will curl up into a tight C-shape if disturbed. On small plants the larvae cut the stems of seedlings at or slightly below the soil surface. One larvae can cut off several seedlings in one evening. On older plants they may eat moderate amounts of foliage with young larvae on terminal growth and older larvae feeding near the ground.

In northern states, economically-important numbers of moths that appear in spring have migrated from

southern states since overwintering black cutworms are rarely abundant enough to cause significant damage. Female moths lay hundreds of eggs either singly or in clusters on low-growing vegetation such as chickweed, curly dock, mustards or plant residue from the previous year's crop. Because of these egg-laying habits, heavy spring weed growth, newly broken sod, and previous crop debris all increase the risk of black cutworm infestations. Generally, black cutworm moths will not lay eggs in fields that have already been planted.

Young larvae (less than ½ inch in length) feed above ground while larger larvae feed at, or just below the soil surface, although in fields with very dry soil conditions the larvae may be found 2-3 inches deep. There are two generations of cutworms per year with the first generation causing the most damage since it occurs concurrently with crop emergence. Excessive rainfall may disrupt egg-laying and flooding may force larvae to the soil surface during the day where they are attacked by parasites or predators.

Carrot weevil (*Listronotus oregonensis*) can cause serious economic damage on carrots but infestations are localized and rare. Adults overwinter in protected areas on field edges or under plant residue. In spring, adults move into germinating carrot fields and lay eggs in cavities excavated in the root crown with 2-3 eggs per cavity. Adult excavations for egg laying can be seen in young carrots. Larvae hatch in 1-2 weeks and tunnel down into roots, feeding for 1-2 weeks before pupation. Primary damage results from the larval tunneling in roots, which may be extensive. There is a single generation in Wisconsin.

Chemical Controls for Insect Pests in IPM & Resistance Management Programs

Aster Leafhopper

No effective biological or cultural controls exist for the management of the aster leafhopper and aster yellows and management programs are based on insecticidal control of vectors.

Incidence ans severity of aster yellows disease depends on three factors: the susceptibility of the carrot variety, the number of aster leafhoppers present and the percent of leafhoppers carrying the pathogen. Using this information, growers can easily compute the aster yellows index (ALI) for the crop and avoid needless insecticide applications. The ALI is calculated as follows: ALI = % infectivity of population X number of aster leafhoppers/100 sweeps. Crops should be monitored weekly with a sweet net to determine population levels. The percent infectivity is currently determined by bioassay of live leafhoppers on aster seedlings. This service is provided by consultants and since infectivity varies between areas and typically changes through the season, bioassays should be conducted regularly. Molecular assays for aster yellows are now available but these tend to generate overly conservative estimates of infectivity and such assays are not currently used in commercial production.

When the AYI is computed, the need to treat is based on the susceptibility of carrot varieties with

treatment recommended at an AYI of 50 for susceptible varieties, 75 for intermediate varieties, and 100 for resistant varieties. Varietal susceptibility is determined by field research and is available through extension recommendations. There is an ongoing need for varietal screening to determine susceptibility of new varieties in use by industry.

An additional leafhopper predictive service is provided annually by UW extension which conducts a spring survey of the leafhopper migration from overwintering areas in the south. Leafhopper numbers, direction of the migration, and infectivity are communicated to growers prior to arrival and ensure that unnecessary applications are avoided.

Since aster yellows symptoms on carrot take 3-4 weeks to develop on mature plants, no treatments should be made within 3 weeks of harvest.

Insecticides to Control Aster Leafhoppers

The aster leafhopper is a highly migratory insect with a wide host range. Since it is rarely treated on many of its host crops (small grains, etc.) Resistance to insecticides is not an important issue and ecological information on development, monitoring and use of the AYI are key elements in avoiding unnecessary applications. The following materials are registered for leafhopper control on carrots with the pyrethroids providing the most effective tool:

Synthetic Pyrethroids

- **Esfenvalerate** (Asana XL)
  is a restricted-use, synthetic pyrethroid pesticide applied at 0.03-0.04 lb a.i./A when the AYI is surpassed. Wisconsin growers tend to use the low end or 0.03 lb a.i./ A. Thorough spray coverage of crown area is essential. Esfenvalerate is the most widely used material for leafhopper control with 93% of the planted acreage (3,700 acres) treated in 1996.

- **Cyfluthrin** (Baythroid EC)
  is a restricted-use, synthetic pyrethroid insecticide that was recently registered for the control of aster leafhoppers, carrot weevils, and black cutworms. Applied at a rate of 0.025-0.044 lb a.i./A, this material provides excellent leafhopper control with greater persistence than esfenvalerate. It should be applied by ground equipment only in sufficient water for complete coverage of foliage. A total of five applications may be made per crop per season with a 7 day interval between applications. It can be applied up to and including the day of harvest. No survey data are available but use has increased in 1997-98.

Carbamates

- **Methomyl** (Lannate L)

is a restricted-use, carbamate registered for the control of aster leafhoppers at rates of 0.5-1.0 lb a.i./A at 5 to 7 day intervals as needed for control. The material is effective but less persistent than the pyrethroid alternatives and the material is not commonly used on carrots in Wisconsin.

- **Carbaryl** (Sevin)
  is carbamate insecticide registered for the control of aster leafhoppers and cutworms at a rate of 1.5 lb a.i./A. This material is effective on leafhoppers but it is less persistent than the pyrethroids and repeated use increases aphid populations. There is no use on carrots grown in Wisconsin at the present time.

Organochlorines

- **Endosulfan** (Thiodan)
  is an organochlorine insecticide registered for the management of aphids and aster leafhoppers at a rate of 0.5-1.0 lb a.i./A. Its use is restricted to one application per season and , since leafhopper efficacy is lower than registered alternatives, endosulfan is not used for leafhopper control in Wisconsin. This material is important, however, for aphid control and its registration should be retained until suitable alternatives are developed.

Insecticides to Control Aphids

Aphids are only a sporadic pest on carrot in the Midwest and infestations are most severe following repeated insecticidal application for aster leafhoppers. Several insecticides are registered for aphid control but none are effective against the green peach aphid.

Organochlorines

- **Endosulfan** (Thiodan, Tracer)
  is an organochlorine insecticide that provides some aphid control at 0.5 to 1.0 lb a.i./A but it may only be applied once. It is used only occasionally in Wisconsin.

Organophosphates

- **Diazinon** (Diazinon EC)
  is an organophosphate insecticide that provides green peach aphid suppression at 0.5 lb a.i./A but repeated use quickly results in lack of efficacy due to resistance. No use of diazinon occurs in Wisconsin unless endosulfan has been ineffective.

- **Malathion** (Malathion EC)
  is an organophosphate insecticide registered for aphid control at a rate of 0.94-1.25 lb a.i./A but,

as with diazinon, provides only suppression and is used rarely.

Insecticides to Control Cutworms

Cutworms are only sporadic pests in Wisconsin with black cutworm being predominant. Several effective materials are currently registered for cutworm control. These should only be used when damaging infestations are present and spot treatments should be used where appropriate. The following materials are registered:

Synthetic Pyrethroids

- **Esfenvalerate** (Asana)
  is a pyrethroid that provides effective cutworm control at 0.03-0.05 lb a.i./A. This material is widely used for aster leafhopper control but is rarely targeted specifically at black cutworm in Wisconsin.

- **Cyfluthrin** (Baythroid)
  is a synthetic pyrethroid that also provides good cutworm control but its use in Wisconsin is primarily for leafhopper control.

Carbamates

- **Carbaryl** (Sevin)
  is a carbamate that provides effective cutworm control as a bait formulation but the pyrethroid alternatives are more effective and no carbaryl bait is currently used commercially in Wisconsin.

Insecticides to Control Carrot Weevils

The carrot weevil is a sporadic pest in Wisconsin and control measures are only required when an infestation has been identified. Since these infestations are rare and localized, little insecticide use is reported annually in Wisconsin. The need for effective materials is paramount when infestations are present however, and when used in conjunction with adult trapping to define infested areas, crop rotation to reduce the potential for infestation and spot spraying of infested areas, registered materials can provide good control. Most often pesticides are used as border sprays only since it is more economically to control carrot weevils in this way.

Effective materials include:

Synthetic Pyrethroids

- **Esfenvalerate** (Asana)
  is a synthetic pyrethroid insecticide used to control carrot weevils at a rate of 0.05 lb a.i./A. Esfenvalerate should be applied with ground equipment in sufficient water to penetrate the crop canopy and reach the developing crowns.

- **Cyfluthrin** (Baythroid)
  is another synthetic pyrethroid insecticide used at a rate of 0.044 lb a.i./A to control carrot weevils. The material should be applied with sufficient water to reach the developing crowns.

Carbamates

- **Oxamyl** (Vydate L)
  is a restricted-use, carbamate labeled for the control of carrot weevils in Wisconsin. It is recommended at a rate of 0.5-1.0 lb a.i./A in sufficient water to penetrate the crop canopy and penetrate the crown.

Weeds

Carrots are well adapted for effective, economical weed control with the use of herbicides. Chemical control is not a substitute for preplant control of weeds or precision cultivation to kill late emerging weeds. However, with proper use and careful timing, herbicides are normally so effective that weeds are not a serious problem.

With the development of bedding systems for carrots, cultivation may be a practical method of weed control--rolling cultivators that guide along the bed allow accurate and relatively fast cultivation. However, while a cultivator will control some resistant weeds, it will not replace chemical control.

There are many **Annual broadleaf weeds** that are problematic in carrot fields. Weed seeds germinate throughout the summer if there is adequate moisture. In the absence of regular moisture, flushes of seed germination often coincide with rainfall events or irrigation. One of the most problematic is pigweed (*Amaranthus spp.*). Pigweed is a vigorous annual that produces a large number of seeds that can survive in the soil for up to 40 years. The most serious species is redroot pigweed (*Amaranthus retroflexus*). Fields with a history of redroot pigweed must have pre-emergence or early post-emergence herbicides applied to prevent outbreaks in the current season.

Another important annual broadleaf is common ragweed (*Ambrosia artemisiifolia*). Ragweed

germination is favored by alternating temperatures, light, and a period of chilling. Ragweed seeds are viable for a long time and can last up to 40 years in the soil.

Common lambsquarters (*Chenopodium album*) is another annual broadleaf weed that poses a problem in carrot fields. It is a very adaptable weed that sets thousands of seeds and, like pigweed and ragweed, can remain in the soil for many years. Most seeds germinate early in the season and early season control is critical. Lambsquarters compete vigorously for nutrients and dense stands of weeds can smother carrot seedlings.

Marestail (*Conyza canadensis*) is another problematic annual broadleaf weed. It thrives in the nutrient-rich muck soils on which carrots are grown. It is a very prolific seed producer and once it sets seeds, re-infestation is likely.

Dodder (*Cuscuta spp.*) is a parasitic annual broadleaf weed that poses scattered problems in carrots. When it is present, it is very serious. Dodder lacks chlorophyll and therefore parasitizes the carrots to obtain nutrients necessary for survival. The leafless stems twine around the host plant forming dense tangles. It robs the crop of nutrients and also interferes with harvest. Light is beneficial for germination, and the seeds remain viable in the soil for 5-10 years.

Smartweed is typically not a primary problem in carrot production but scouting observations report that it is becoming problematic on sandy soils particularly in low-lying areas.

Annual grasses also pose a concern in carrot fields because of their vigorous growth and ability to produce copious amounts of seed. They are also very tolerant of moisture and temperature extremes once they become established. If uncontrolled, grass weeds can root and branch from the lower joints and stems. All annual grasses should be controlled before they set seed. Some of the most problematic grasses are the foxtails (*Setaria spp.*). Foxtails germinate in early spring and throughout the growing season. They have a very rapid life cycle, with an average of 37 days from seedling to 25% flowering. The seeds can remain viable for 5-10 years in the soil.

Crabgrass (*Digitaria spp.*) are another group of annual grass weeds that are a problem in carrot fields. The worst crabgrass infestations occur after cultivation. Crabgrass germinates anytime from in mid-spring to late summer with an optimum temperature between 68 and 95F favoring warmer soil temperatures than foxtails.

Barnyardgrass (*Echinochloa crusgalli*) is warm-season annual grass. It is adapted to wet soil conditions. It responds to short days by quickly flowering. Its seeds remain viable for 2-4 years in the soil.

There are some **perennial weeds** that affect carrot fields. One of them is swamp smartweed or devil's shoestring (*Polygonum spp.*). It is very adaptable, thriving on both wet and dry soils. Optimum germination occurs when temperatures alternate between 68 - 85F. It is propagated by seeds and creeping rhizomes.

Sedges can be a key weed in carrot production. They are not a widespread problem, but when an infestation occurs, it can be the most serious pest on muck and mineral soils. Even light infestations can reduce growth and root size. The plant reproduces by seed and underground tubers called nutlets. The underground tubers can overwinter and survive soil temperatures of -20F. The tubers sprout from May to late July and each sprouting tuber is capable of producing numerous plants.

Chemical Controls for Weeds in IPM & Resistance Management Programs

Carrots have few alternative herbicides. Linuron is the herbicide of choice because of it's ability to be used as a pre- or post-emergence treatment. It can be used as a post-emergence treatment in IPM scouting programs when weeds are present.

Grass Herbicides

- **Fluazifop-P-butyl** (Fusilade DX)
  is an systemic herbicide that controls emerged grasses. It is applied as a post-emergent treatment to actively growing weeds at a rate of 0.13-0.19 lb a.i./A and 0.5 - 0.75 lb commercial product / A. One of the following should always be added to the finished spray volume: 1% crop oil concentrate or 0.25% anionic surfactant. Multiple applications can be made but not to exceed 48 fluid ounces of Fusilade Dx per acre per season. There is a 45 day pre-harvest interval that must be observed. Cultivation of treated grasses is not recommended within 7 days prior to, or within 7 days after, application as weeds may be stressed, reducing weed control. Timely cultivation 2-3 weeks after application may help weed control. Fluazifop-P-butyl can be applied by ground, aerial, band or chemigation methods. It was applied to 100% of the carrot acreage planted in 1996 to control the cover crop as well as controlling annual grass weeds. A total of 400 lbs were applied an average of 1.2 times at an average rate of 0.14 lbs/A. If fluazifop-P-butyl lost it's registration for use in carrots, hand cultivation would be substituted in 40% of the carrot acreage at a yield reduction of 20%. Mechanical cultivation would be substituted in 100% of the acreage for an additional yield reduction of 30%.

- **Sethoxydim** (Poast)
  is post-emergent herbicide registered for control of actively-growing, emerged grass weeds at a rate of 0.10 - 0.47 lb a.i./A or 0.5 - 2.5 pt commercial product/A. It may be broadcast, banded, spot sprayed or aerially applied to the foliage of grasses on a spray-to-wet basis. There is a 30 day pre-harvest interval. broadcast, aerial, band, or spot spray applications. Crop oil concentrate at a rate of 1 qt/A should always be added to the finished spray mix. Multiple applications may be made allowing 14 days between applications, but do not apply more than 5 pt/A of Poast per season. Poast was applied once by ground application to 50% of the planted acres in 1995. If Poast were unavailable, 20% of the acreage would be hand cultivated and 100% of the treated acres would be cultivated for a total yield reduction of 30% as a result.

Broadleaf & Grass Herbicides

- **Linuron** (Lorox)
  is registered for control of annual broadleaf weeds and some grasses. It is labeled at a of 0.75-1.5 lb a.i./A with Wisconsin growers tending to make applications at the low end of the recommended rate. A single pre-emergent application of 1 to 3 lbs Lorox per acre can be made after planting but before carrots emerge. Pre-emergent applications of linuron should not be incorporated. A higher rate should be used for those fields that are higher in organic matter. Postemergent applications are made when carrots are at least 3 inches tall but before broadleaf weeds are 6 inches tall and grassy weeds exceed 2 inches. It is recommended that tolerance to linuron be determined before use in the field since carrots vary in their resistance. Subsequent postemergent applications may be made provided the total does not exceed 4 lbs Lorox DF or 4 pts Lorox L and Linex 4L per acre per season. For control of marestail, it is applied at a rate of 0.5-1.5 lb active ingredient per acre for a single pre-emergent application only. Linuron was applied to 100% of the carrots planted in Wisconsin in 1996. 5,500 lbs were applied an average of 4 times at an average rate 0.4 lbs/A. If linuron were to lose its registration for use on carrots, there would be no substitutes on muck and Wisconsin growers would realize a 100% loss in yield. On sandy soils, trifluralin could be substituted.

- **Trifluralin** (Treflan MTF)
  used to control annual grasses and broadleaves. It is applied at a rate of 0.5 - 1.0 lb a.i./A on mineral soils only as it is ineffective on peat and muck soils. Applications of trifluralin are preplant-incorporated to control annual grasses and many broadleaf weeds. It should be incorporated within 24 hours of application. It should be incorporated at least 2-3 inches deep into the top of the final seed bed. A second incorporation should be delayed a minimum of 5 days after the first and be completed before planting for best weed control results. Treated crops may be shallowly cultivated without loss of weed control activity. Deep cultivation that could bring untreated soil to the surface and result in a loss of weed control. Wild mustard, smartweed, common ragweed, velvetleaf, and black nightshade may escape control. Trifluralin is not used in Wisconsin since most carrots are grown on muck soils and this herbicide is not effective on this soil type.

- **Metribuzin** (Sencor 4, DF)
  is a post-emergent herbicide for control of emerged annual broadleaves and certain grasses. It is applied at a rate of 0.25 lb a.i./A or 0.5 pt/A Sencor 4 or 0.33 lb/A Sencor DF after carrots have formed five to six true leaves but before weeds are 1 inch in height or diameter. If needed, a second application may be made after an interval of at least three weeks but not to exceed 0.5 lb a. i./A in one season. In Wisconsin, metribuzin is used below labeled rates to enhance the activity of linuron on weeds that are otherwise difficult to control. There is a 60 day pre-harvest interval and there is a plantback restriction of one application per season if carrots are rotated with onions. Sencor should not be applied within three days of any other chemical or within 14 days of any

other pesticides when carrots are under stress. For carrots with an unknown tolerance to Sencor, treat only a small area initially.

Metribuzin was applied to 75% of the 3,700 acres of carrots planted in Wisconsin in 1996. 300 lbs was applied an average of 1.5 times by ground application at an average rate of 0.08 lbs/A. If there was no label for metribuzin in carrots, 20% of the acreage would be hand cultivated at a yield loss of 10%. Additionally, 100% of the acreage would be mechanically cultivated for an additional yield loss of 30%.

- **Glyphosate** (Roundup)
  is a pre-emergence herbicide registered control for emerged annuals and perennials at a rate of 0.28 - 1.12 lb a.i./A or 12-48 oz commercial product per acre. If weeds have been mowed or tilled, plants should not be treated until they have resumed active growth and have reached the recommended stage on the label. There is a 14 day pre-harvest interval. Glyphosate is only used occasionally on stale seed beds or before planting to control problem weeds.

Outlook for New Registrations

Since no effective aphicide is available for carrots, the development of effective materials is a high priority. Pirimicarb (Pirimor) and pymetrazine (Fulfil) are potential alternatives.

A new label for Quadris (azoxystrobin) is the first of several new fungicides that will benefit carrot growers in Wisconsin. The combined use of azoxystrobin at 0.1 lb a.i. with chlorothalonil can reduce the amount of chlorothalonil by one-half. However, the label for chlorothalonil on carrots cannot be lost as the sole dependance on one fungicide (azoxystrobin in this case) will result in the development of disease resistance problems.

Diseases

Alternaria leaf blight (*Alternaria dauci)* is a common foliage disease of carrots. In warm, moist weather, leafspotting progresses so rapidly that the entire field may resemble frost or chemical injury. Alternaria blight is often confused with, and commonly occurs with Cercospora blight. However, the Alternaria fungus generally attacks older foliage and is seldom serious until plants approach maturity. Petioles of leaves weakened by both blights become brittle and often break off during harvest, and depending on the type of harvester used, may result in unharvestable carrots. *Alternaria dauci* overwinters in diseased debris in the soil. It may be spread on or in contaminated seed. During the growing season, *Alternaria* spores and mycelium are disseminated by wind, water, splashing rain, and

equipment. Infection takes place rather slowly unless a favorable environment is present. Moisture is needed for germination and infection, whether it be heavy dews or rain. The optimum temperature for fungal growth and infection is 83F. When wounds are present, symptoms develop much more quickly.

After infection occurs, small, dark brown to black spots with a chlorotic border form along leaflet margins. The entire leaflet shrivels and dies causing the foliage to appear burned as the irregularly shaped lesions increase in size and number. Large, elongated lesions may form on the petiole, girdling and killing the entire leaf before any spots develop. Alternaria also causes damping-off of seedlings, blight of seed stalks, and a black decay of the roots. Initially, the disease occurs irregularly, in small patches within a field. Symptoms resemble frost injury or Lorox (herbicide) burn. Later, Alternaria blight becomes fairly uniform throughout the field. Alternaria can be distinguished from Cercospora blight in the field by the irregularity of lesion shape and dark brown color of the spots.

Aster Yellows causes severe losses in yield and quality of carrots. It affects both the above- and below-ground portions of carrot plants. The disease was first described on asters in 1902 and has since been described on a wide range of host plants. Aster yellows is caused by aster yellows phytoplasma and is transmitted to plants by at least 17 species of leafhoppers but is primarily transmitted by the aster leafhopper. There is no control for aster yellows once plants become infected therefore growers must prevent aster yellows by controlling the leafhoppers with the use of insecticides, by planting tolerant varieties, and by sound cultural practices.

The pathogen overwinters in the bodies of adult leafhoppers or in perennial host plants such as weeds and ornamentals. In Wisconsin, leafhoppers first appearing in the spring are blown in from southern and southwestern areas. After the nymph or adult leafhoppers acquire the phytoplasma, a minimum of ten days must elapse before they are able to transmit the disease. The phytoplasma multiplies in the insect, and the insect may remain infective for at least 100 days after acquiring the pathogen. When infected leafhoppers are exposed to 88F for several days, they lose their ability to transmit aster yellows. This suggests that the effect of summer heat on the vectors is responsible for the decrease in transmission during warm weather. The time of appearance of the disease in carrots is directly correlated with the flights of leafhoppers from diseased plant reservoirs to young plants. By monitoring the migration of these early-season vectors and determining the population level and number of infective individuals, growers can estimate the likelihood of damage to crops.

After infection, initial symptoms appear within 10-21 days. The first symptom on carrots is yellowing and vein clearing of young leaves at the center of the crown. Next, dormant buds in the crown break and grow into chlorotic shoots which give a witches' broom or short, bunchy appearance to the top. Old leaves become twisted and reddened or bronzed and eventually break off, leaving the top to consist of only short adventitious shoots. These plants are difficult to harvest mechanically and bunch for market. Size and quality of roots are reduced. Carrots are usually malformed and numerous hairy secondary roots develop. There is a woodiness or toughness, off-flavor, and poor color (pale orange vs. dark orange) are associated infected roots. The crowns of the diseased plants are predisposed to soft-rot bacteria in moist weather. When affected carrot roots are used for seed propagation, the plants often die

before the seed is mature.

Cercospora leaf spot/blight (*Cercospora carotae*) is an important foliage disease of carrot but it does not affect the edible carrot root. It is severe on young leaves and develops rapidly when plants are relatively young. Cercospora blight can be controlled by cultural practices, disease-tolerant cultivars, and through the use of fungicides. The fungus overwinters on infected plant debris and wild hosts such as Queen Anne's Lace. Spores are produced on this debris and are carried by wind or water to young carrots. The fungus enters the plant through stomata. Lesions appear in 3-5 days and new spores are produced soon thereafter.

Although lesions develop on the leaves and cause a lateral leaf curling, Cercospora may attack any aerial part of the plant. Leaf lesions are small and circular while petiole lesions are elliptical. Small lesions coalesce into large necrotic areas until the whole leaflet dies. During humid weather, the lower surface of the lesion becomes light gray as a result of spore masses. Eventually the petiole may be girdled and the leaf killed. When floral parts of carrots grown for seed are infected early, they shrivel before the seed is produced. If floral parts are infected later, the fungus may enter the seed and become a threat to the next year's crop.

Cottony soft rot (*Sclerotinia sclerotiorum*), also called white mold or watery soft rot, is a destructive fungus found worldwide that causes severe losses on stored carrots. The initial infection generally occurs in the field, but may not produce characteristic symptoms until after harvest. Crown infection makes harvest difficult to impossible depending on the severity of infection. In storage, the disease spreads rapidly from infected roots to healthy ones.

White mold can survive in the soil for many years as black sclerotia. It can also live from season to season as active mycelium in living or dead plant tissue. Infection occurs during periods of cool, wet weather. Sclerotia germinate in moist soils to produce ascospores which are carried from plant to plant and field to field by wind. Penetration into the plant by germinating ascospores is direct and wounds are not necessary for infection to occur. Enzymes produced by the fungus cause plant tissue to dissolve and become soft and watery.

Infection often begins at the base of the petiole and spreads rapidly to other parts. The petioles turn brown and the tissue collapses and dies. Early lesions resemble those caused by *Rhizoctonia* however, the lesions of the latter are sunken and firm. Furthermore, white mold can be positively identified by the presence of small, black sclerotia. Under moist conditions, a white cottony mycelium appears on infected plants. In advanced stages, small, black sclerotia appear on the petioles. A crown infection usually follows and continues development in storage. Infected tissues darken as they decay, becoming soft and watery without sliminess. The tissue may become slimy if secondary bacteria invade decaying tissue.

Chemical Controls for Diseases in IPM & Resistance Management Programs

Carrots in Wisconsin are frequently scouted as part of a pest monitoring program. As such, reduced pesticide use has been realized. However, it is necessary that we continue to have available, effective, fast-acting protectant fungicides for use when disease monitoring programs warrant.

Chlorothalonil will be a necessary component in rotation with Quadris in the future for control of foliar diseases on carrots to prevent the development of resistant strains of the pathogen.

Several new aster yellows-resistant inbred lines have been released. These lines are currently being used in the seed industry as parents for hybrids. The lag time between inbred release and hybrid appearance could be as long as 5-6 years.

Crop rotation out of carrots into sweet corn, field corn or oats for 1-2 years will also reduce populations of nematodes in an infested field.

- **Benomyl** (Benlate 50WP)
  is a benzimidazole fungicide registered for the control of Sclerotinia white mold. It is applied by ground equipment or through irrigation systems at a rate of 0.5-1.0 lb commercial product/A. There is a 4 day pre-harvest interval that must be observed. No more than 3.0 lbs a.i. should be used per acre per season. Very little benomyl is applied to carrots in Wisconsin but for those growers who use it, it is an important part of their disease management program.

- **Chlorothalonil** (several formulations - Bravo, Terranil)
  is a fungicide registered to control Alternaria and Cercospora leaf blights. It is applied at a rate of 1.5- 2.0 pt commercial product per acre by either ground or aircraft. Applications should begin when disease threatens and repeated at 7-10 day intervals as necessary to maintain control. There is no pre-harvest interval for chlorothalonil on carrots. In 1996, 93% of the carrot acreage was treated with chlorothalonil an average of 6 times with a total of 24,200 lbs.

- **Copper hydroxide** (Champ, Kocide DF, 1000DF)
  is a fungicide registered to control Alternaria and Cercospora leaf blights. It is applied at a rate of 1.5-2.0 lb commercial product/A beginning when disease first appears and re-applied on a 7 to 14 day interval for as long as necessary. It may be applied as an aerial, ground dilute or ground concentrate spray. There is no pre-harvest interval that must be observed. Copper hydroxide is not an important fungicide for carrot growers except certified organic growers.

- **Iprodione** (Rovral)
  is labeled for the control of Alternaria leaf blight. It is applied at a rate of 1.0-2.0 lb commercial product/A with first application made as soon as conditions become favorable for disease development with repeat applications made every 7 to 14 days as long as conditions favor disease development. No more than 4 applications should be made per season and there is a one day pre-

harvest interval. Iprodione is not an economical fungicide for Wisconsin growers.

Nematodes

Root Knot Nematode (*Meloidogyne hapla*) is a microscopic, plant parasitic roundworm found in soil throughout the country. It is particularly common in muck soils, where it attacks many crops. Carrots in particular, are severely damaged by the nematodes as they feed on the root tip and rootlets. Quality requirements for carrot production dictate long and smooth roots, which is compromised when nematodes are present at low densities (less than 40/100 cu cm soil). Nematodes affect foliage growth, weight, and length of the storage portion of tap roots, and induce malformations of tap roots. Unmarketable roots are forked, knobby, hairy and misshapen. Severely infected roots may be completely decomposed by secondary pathogens. When young seedlings are attacked, stand loss may result. Infected plants occur in pockets in the field ranging in size from a few feet in diameter to acres. Crop rotation, with periodic soil fumigation is recommended for controlling the root knot nematode.

The root knot nematode must feed on the roots of susceptible plants to produce and complete its life cycle and reproduce. If the optimum soil moisture is present, some larvae or eggs may survive in the soil for several years. However, alternate freezing and thawing is often detrimental to the larvae. Eggs are fertilized and develop within the body of an adult female. Before egg hatch occurs, the larvae molt within the eggs so that the larvae that emerge from the eggs are actually stage II larvae. It is the stage II larvae that invade the roots and cause infection. The nematode moves mainly by surface water drainage, blowing soil, and by equipment. Within the plant, the larvae undergo 3 additional molts before becoming reproductively mature. Adult males leave the roots on search of mates and the cycle begins again. Nematodes can reproduce indefinitely in the presence of susceptible crops or weeds. A new generation occurs every 25 days under favorable conditions. In less favorable conditions, generation time may be as long as 30-40 days.

Aknowledgements

This crop profile was written by K. A. Delahaut of the Wisconsin PIAP Program and reviewed by Dr. Larry Binning, Vegetable Weed Scientist, Paul Miller, Dr. Walt Stevenson, Vegetable Plant Pathologist, Mr. Rand Van Haren, Pest Pros Consulting Service, Dr. Jeffrey Wyman, Vegetable Entomologist, and Dennis Zeloski.

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