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Florida Crop/Pest Management Profiles: Carrots[1]

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Production Facts

- Florida was ranked fourth nationally in the production of fresh market carrots in 1997 and has typically ranked between fourth and sixth in terms of production and/or crop value (1-3).

- Cash receipts from Florida carrots totaled over $16.3 million in 1997 and ranged from $11.2 million to $25.5 million during the previous 5 years (4). In 1996, Florida's contribution represented 3.7 percent of total U.S. cash receipts for carrots (3). Over the period 1988-93, Florida's harvested acreage accounted for an average of 9 percent of total U.S. carrot acreage (5).

- During the 1997-98 production season in Florida, a total of 6,800 acres of fresh market carrots were planted and 5,600 acres were harvested, with an average yield of 12,500 pounds per acre. A total of 70 million pounds of carrots was produced, with a value of $0.162 per pound and a total value of $11.34 million (2). During the previous season (1996-97), Florida growers experienced record high carrot yields, with 18,500 pounds produced per acre, for a total of 120.3 million pounds from 6,500 harvested acres. Over the last ten years, carrot acreage in the state has been declining, while at the same time average yield per acre has been generally increasing. For example, in 1987-88, over 12,000 acres of carrots were harvested in Florida, with an average yield of 9,700 pounds per acre (6). Recently, carrot production ceased in one of the principal carrot producing areas of the state (Zellwood area around Lake Apopka), and carrot acreage dropped considerably.

- Nearly all carrot production in Florida is for the fresh market. Occasionally processors contract in Florida to meet their demand, but the amount of production for processing varies annually. Florida no longer produces whole baby carrots, although some production of carrots for baby food continues (7,8).

- Yields in Florida tend to be lower than in states where more production goes toward processing, because yields for fresh market carrots are lower than those for processing carrots. At the same time, the total value of Florida's carrot crop is

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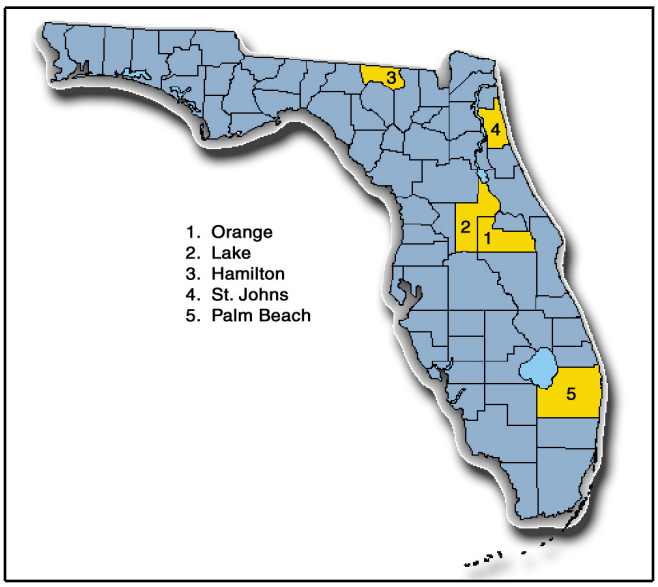
generally higher than in other states, because prices for processing carrots are only about one-third the price of carrots for the fresh market (5).

- Farms producing carrots commonly produce other vegetable crops as well. Carrot sales typically represent about one-fifth of all sales for farms that produce carrots in Florida, with carrot acreage comprising about one-third of total vegetable acreage (5).

- Costs for pest control chemicals represent approximately 8 percent of total farm production expenses for carrot producing farms in Florida (9).

Production Regions

Previously, Florida's carrot production was centered around Lake Apopka, in the Zellwood area of north-central Florida (Orange and Lake Counties), with some production near the southern tip of Lake Okeechobee (5,6). When the Zellwood acreage was lost, approximately one-quarter of the production acreage moved to north-east Florida (Hamilton and St. John's counties) and south-central Florida (7). This accounts for several hundred acres and is primarily for fresh market (10). The shift in production is recent, and therefore pesticide usage data included in this profile is reflective of previous production on primarily organic soils.



Major Carrots Production Region in Florida.

Production Practices

Although carrots in Florida were previously grown primarily on organic muck soils, most carrot production is now on the inorganic, mineral-based soils of north Florida. Mineral soils produce higher quality carrots (7).

With both a winter and spring crop, Florida carrot producers plant between August 15 and February 15, with most active planting in August (north and central Florida) and September (south Florida). Harvest can occur from November 1 to June 10, with the most active time of harvest being between December 15 and May 25 (6,11). Seventy percent of the total harvested area of carrots in Florida is harvested during the winter season (November to March), and 30 percent is harvested during the spring season (April to June) (2).

Some of the carrot varieties used in Florida include Apache, Six Peace, Choctaw, and Navajo (long types), as well as processing types provided by the processor. Carrot seeds are planted to stand, with between 2 and 4 pounds of seed per acre planted at a depth of one-quarter inch. Usually, rows are planted in groups of 3, with 1.5 inches (3.8 cm) between each row and twelve inches (30 cm) between 3-row groups. Occasionally, seed is randomly scattered over a 3-inch band, instead of planting 3 rows together, but more acreage is planting with the 3-row method. Plant population is approximately 350,000 per acre (8,11). Carrots were usually planted in beds in the previous production regions, but beds are not used in the mineral soils of north Florida (7,8,12). Carrots in Florida reach maturity between 90 and 165 days after planting (7,8). One hundred percent of carrot acreage in Florida is irrigated (5).

On the muck soils of previous production regions, approximately 70-96 percent of carrot acreage was receiving approximately 24-41 pounds of nitrogen per acre, in an average of 1 application annually (13). Approximately 100 to 150 pounds of nitrogen per acre are applied to sandy soils (8). During previous production on muck soils, approximately 67-100 percent of acreage received 1 application of phosphorous annually, with 31-71 pounds per acre utilized at each application. Between

77 and 157 pounds of potash per acre were applied once annually to 70-100 percent of carrot acreage in Florida (13). Micronutrients important to carrot production, such as boron, manganese and copper, which tend to be deficient in organic soils, were applied at the same time as the macronutrients, or later in a foliar spray (5). However, data on application of macronutrients in current production regions is not yet available. Also, on the inorganic mineral soils in which carrots are presently produced, micronutrients may not be deficient, and their application is not as critical (10).

Carrots are machine harvested and shipped without the tops, since the tops can accelerate shriveling by withdrawing moisture from the roots. Although carrots in other states are often harvested by digging, Florida growers utilize a mechanical harvester that lifts the carrot and pulls the tops to harvest. Top vegetative growth is crucial to the harvest process. Most growers harvest their own crop and serve as their own packer-shipper or join together, usually informally, as packer-shippers. Formal contracts with packer-shippers are not usual for carrots in Florida (5,10).

Insect/Mite Management

Insect/Mite Pests

There are no major insect pests on carrot in Florida. The greatest concern for growers has been root damage from soil pests, particularly wireworms (southern potato and tobacco), cutworms (variegated, granulate, black), and mole crickets, all of which are sporadic. Occasional minor pests include leafminers (especially the vegetable leafminer), aphids (green peach and melon), and weevils (especially vegetable weevils). Other arthropods that may occasionally cause minimal damage to carrots in Florida include armyworms (fall, beet, and southern), field crickets, mites (especially twospotted spider mite), and plant bugs (including tarnished plant bug) (7,8,14-16). Growers utilize several Integrated Pest Management (IPM) strategies in their pest management program.

Wireworms. Wireworms, a sporadic pest on carrots in Florida, are a greater problem on organic soils than on mineral soils. These hard, slender larvae of the click beetles can be found throughout the root zone. Living up to several years, they can attack the developing carrots directly, causing severe loss, or can provide entry points for pathogens that cause secondary rots. Poison baits are often used for wireworm control (7,14,17).

Cutworms. Cutworms, another sporadic pest of carrots in Florida, can be a problem during seedling establishment. Cutworms are thick, dark caterpillars whose adult stage is a moth related to that of armyworms. They attack young seedlings, most actively at night, and may cut the stem off at the base. During the day, they remain hidden in debris on or just under the soil surface. Pyrethroid sprays and to some extent poison baits are commonly used to manage cutworms (7,8,14,17).

Mole Crickets (*Scapteriscus* species). Mole crickets of the introduced genus *Scapteriscus* can damage vegetable seedlings throughout the southeastern United States. Both the short-winged mole cricket (*Scapteriscus abbreviatus*) and the tawny mole cricket (*Scapteriscus vicinus*) can damage vegetables in Florida. Mole crickets are most active at night, tunneling in and around the roots of young plants. Although some damage occurs from their feeding on the roots and on the stems and leaves of young plants, mole crickets are most damaging to carrot plants when they cut the stems of seedlings at or near ground level. On warm nights when the soil is moist, both nymphs and adults feed above-ground (17-19).

Most of the mole crickets' life cycle is completed underground. The tawny mole cricket has been the most studied mole cricket in Florida, where it completes one generation per year. Eggs are laid from April to June in underground chambers from 4 to 12 inches (10 to 30 cm) belowground. Females may each lay several clutches of eggs, containing 24 to 60 eggs apiece. After the female closes the chamber entrance, the eggs incubate for approximately 3 weeks. Upon hatching, mole cricket nymphs tunnel out and feed on plant roots, growing and molting 6 or 7 times during the summer months. Most reach the adult stage during the fall, overwinter, and breed the following spring. Springtime flights in Florida occur between February and April, beginning and ending several weeks earlier in south Florida than

in north Florida. Although damage from the short-winged mole cricket is similar to that from the tawny mole cricket, its life cycle is less well understood. Egg-laying usually peaks in late spring or summer and to a lesser extent in winter, but all life stages appear to occur throughout the year (19).

Since they prefer light, sandy soils or heavier soils that have been cultivated, mole crickets can occur in soils throughout Florida. However, they are primarily a problem on mineral soils. As carrot production moves to north Florida, mole crickets may become a more important pest. Diazinon is the principal insecticide used to control mole crickets on carrots in Florida (7,8,17).

Leafminers (*Liriomyza sativae* and *Liriomyza trifolii*). Leafminers, particularly the vegetable leafminer (*Liriomyza sativae*) and occasionally the American serpentine leafminer (*Liriomyza trifolii*), which attack a variety of vegetable crops, are a sporadic foliar pest on carrots in Florida. They are a problem on seedlings during the fall carrot season. Adult leafminers are very small flies, the females of which deposit their eggs within the leaf tissue. The tiny yellow maggots feed on the inner leaf tissue, leaving a winding (serpentine) tunnel behind them. In Florida, leafminer generations are continuous during most of the year. Although healthy plants can usually tolerate substantial leafminer damage, heavy damage may cause leaf drop. Also, the exit holes in old mines may provide access to pathogens. Chemical control of leafminers is difficult, because during the feeding stage the pest remains protected within the leaf. Several parasitic wasps naturally keep populations below damaging levels in Florida in the absence of broad-spectrum insecticide use (8,14,17).

Aphids. Aphids are also a minor and sporadic pest on carrots in Florida. The green peach aphid (*Myzus persicae*) is the species most often reported on the crop in the state. The melon aphid (*Aphis gossypii*), which has a wide host range, may also be found on carrots. The aphid *Hyadaphis coriandri*, which has recently been found in Florida, is damaging to several umbelliferous herbs and is capable of colonizing carrots, but there has been no state report on carrots (14,20,21).

Aphids feed by piercing plant tissue with their needle-like mouthparts and sucking out water and nutrients. Toxins in their saliva, which can be injected into the plant tissue during feeding, may cause foliage to curl and deform. Aphids also deposit large amounts of honeydew on the plant surface, which encourages the growth of black sooty mold. A short life cycle and reproduction by asexual means and by live birth allow aphid populations to increase rapidly in Florida (17).

Chemical Control

Insecticides are rarely used in Florida carrot production except to protect seedlings from cutworms, wireworms and mole crickets (7). However, eighty percent of Florida carrot acreage received some insecticide applications in 1996, with a total of 14,900 pounds of active ingredient applied (22). The most commonly used insecticides are diazinon (Diazinon), methomyl (Lannate®), and esfenvalerate (Asana®) (13). Additional available products that may be used on occasion in carrot production include *Bacillus thuringiensis* (Javelin®), carbaryl (Sevin®), cyfluthrin (Baythroid), cythion (Malathion), dichloropropene (Telone II), endosulfan (Thiodan), methoxychlor (Methoxychlor), methyl parathion (Penncap-M®), pyrethrins plus piperonyl butoxide (Pyrenone®), pyrethrins plus rotenone (Pyrellin®), and rotenone (Rotacide®) (16).

Diazinon (Diazinon). Diazinon is an organophosphate insecticide used by carrot growers for the management of cutworms, wireworms, and mole crickets. It is incorporated into the soil before planting. The median price of diazinon is $8.40 per pound of active ingredient (23). Diazinon may be applied up to 10 days before harvest (PHI=10 days), and the restricted entry interval (REI) under the Worker Protection Standard is 12 hours.

During the years in which usage data has been collected, carrot growers have applied diazinon to a range of 41 to 52 percent of the state's total acreage. Growers have applied an average ranging from 1.69 to 4.29 pounds of active ingredient per acre, an average of once per year. Total diazinon usage on carrots has ranged from 7,400 to 16,400 pounds of active ingredient annually (13). Diazinon 14G is the

most common formulation, and one grower has reported recent usage of 20 pounds of active ingredient per acre to 100 percent of carrot acreage (8).

Methomyl(Lannate®). Methomyl is a carbamate insecticide used in Florida primarily to manage beet armyworm. The median price of the most commonly used formulation of methomyl on carrots in Florida is $20.21 per pound of active ingredient (23). Methomyl may be applied up to 1 day before harvest (PHI=1 day), and the restricted entry interval (REI) under the Worker Protection Standard is 48 hours.

During the years in which usage data has been collected, carrot growers in Florida applied methomyl to a range of 27 to 40 percent of the state's total carrot acreage, an average of 1.1 to 2.0 times annually. Growers used an average range of 0.22 to 0.46 pounds of active ingredient per acre at each application, with total usage in Florida ranging from 800 to 1,600 pounds of active ingredient annually (13). One grower recently reported one application to 25 percent of carrot acreage (8).

Esfenvalerate (Asana®). Esfenvalerate is a synthetic pyrethroid insecticide occasionally used by carrot growers in Florida. It is the principal insecticide used for the management of cutworms (8). The median price of the most commonly used formulation of esfenvalerate on carrots in Florida is $199.67 per pound of active ingredient (23). Esfenvalerate may be applied up to 7 days before harvest (PHI=7 days), and the restricted entry interval (REI) under the Worker Protection Standard is 12 hours.

In 1996, growers applied an average of 0.04 pounds of active ingredient per acre, an average of 1.1 times, to 55 percent of the state's carrot acreage. Total esfenvalerate usage in that year was 200 pounds of active ingredient. (13). One grower recently reported one application to 80 percent of carrot acreage (8).

Cultural Control

Flooding the field during the summer fallow, which was viable in the former muck production areas, has effectively controlled wireworms and other soil insects. However, with the transition from production on organic soils to the inorganic mineral soils of north Florida, flooding is no longer a feasible method of cultural control for most carrot growers. North Florida carrot production will likely require greater insecticide inputs for the management of soil insects (10,14).

Biological Control

Severe damage to Florida turfgrass, pasture grass and vegetables from mole crickets has led to the development of several biological control activities in the state. The tachinid fly *Ormia depleta* has been evaluated for use in a classical biological control program for mole crickets, with initial releases made at Gainesville and Bradenton in 1988 and subsequent releases in other counties through 1992. Populations of the fly became established from Dade to Alachua counties but no farther north. This program is still in the experimental stage, with some work focusing on provision of appropriate nectar sources for the fly (18,19).

Presently, the most effective biological control agent for mole crickets is a steinernematid nematode introduced from South America. The parasitic nematode *Steinernema scapterisci* has shown promise for managing mole crickets in pasture and turf in Florida, and in the past has been available commercially for mole cricket control in turf. *Steinernema scapterisci* has been shown to be highly effective against tawny mole crickets and less effective against short-winged mole crickets. It is most effective as a biocontrol agent where mole cricket populations are highest, as in pastures. It can also be used as a biopesticide where mole cricket populations are lower, and it shows residual activity. The nematode is able to disperse well when applied and has shown good recovery years after its application. Populations have become established in small areas of several Florida counties. If it becomes established in pastures surrounding vegetable crop production areas, it is expected to keep mole cricket populations below damaging levels (18,19,24).

Disease Management

Disease Pathogens

Diseases constitute the most important pest type for carrot production in Florida. The most common diseases attacking carrots in Florida include Alternaria blight, cavity spot, damping-off, Pythium brown rot, Sclerotinia rot, and bacterial blight. Southern blight (*Sclerotium rolfsii*) can be severe when it occurs. Gray mold (*Botrytis cinerea*) and bacterial soft rot (*Erwinia carotovora*) are minor diseases on carrots in Florida, and Cercospora leaf spot is only occasionally seen (7,33-36).

Alternaria Leaf Blight (caused by *Alternaria dauci*). Alternaria leaf blight is the most important carrot disease in Florida and is often the only disease against which growers will apply chemical treatment. *Alternaria* produces dark spots with yellow borders, which can destroy entire leaflets or leaves. The disease can also cause root decay. The fungus is transmitted by seed, so ensuring disease-free seeds can aid in preventing its introduction into the field. Other infected crop plants or weeds can also be the source of the fungus, and once it infects the plant, developing spores can be dispersed within the crop by wind or water. Disease development is favored by cooler weather (33-36).

Southern Blight (caused by *Sclerotium rolfsii*). Southern leaf blight can be a major problem for carrots on mineral soils, so it is likely to increase in importance as a carrot disease in Florida, as production moves to the mineral soils of north Florida (7). Southern blight is a warm weather disease that attacks a variety of vegetable crops. When seedlings are affected, they may die. In older plants, symptoms first appear as yellowed or wilted leaves. As the disease advances, a cottony white mass of mycelium is seen as the fungus advances up the stem and down into the root system. Infection is greatest at or near the soil line. From infected tissues, the white mycelium moves over the soil, where it can initiate infections on adjacent plants. The fungus can survive in the soil as sclerotia and is spread in water, soil or infected plant parts. Disease development can be rapid under conditions of high temperature and moisture (34).

Cavity Spot (caused by *Pythium* spp.). Cavity spot can be an important disease in carrot production in Florida when it occurs, because it produces lesions on the roots, making the carrots unsaleable. Initially appearing as tiny, sunken spots, the lesions enlarge as the plant matures. The lesions tend to occur more frequently on the upper third of the tap root. The soilborne pathogen *Pythium*, which causes the disease, is favored by cool temperatures and wet conditions. Disease severity can also be greater when there is excess nitrogen in the soil, when the temperature is unfavorable for the plant, and when carrot is planted consecutively for several years (34,37).

Damping-off (caused by *Rhizoctonia*, *Pythium*, *Fusarium* and *Sclerotinia* species). Damping-off is a root disease that affects carrot plants through the seedling stage. The extent of damage depends on soil moisture, temperature and other factors. The disease can affect older plants, but damping-off injury is greatest in seedling roots during germination. Poor germination or emergence of seedlings results. When older plants are infected, they experience root rots and poor growth, which may result in considerable yield reductions (33,34).

Pythium Brown Rot (caused by *Pythium* species). Pythium brown rot is a root disease that is sometimes a problem in Florida. When plants are infected early, seedling blight results. Older plants are affected primarily at the root tip, producing extreme root branching. Plants also experience wilting, stunted growth and often yellowing in lower leaves. Pythium brown rot can greatly reduce carrot yields, producing rough and hairy roots. Severity of the disease is greater under conditions of prolonged high soil moisture, soil temperatures not optimum for the host plant, excessive soil nitrogen, or where the crop has been grown for several consecutive years in the same field (33,34).

Sclerotinia Rot (caused by *Sclerotinia sclerotiorum*). Also called white mold, sclerotinia rot produces a white fluffy growth on the infected plant. Following establishment of the fungus at the base of the leaf stalk, leaves begin to wilt and die, eventually producing hard, black resting bodies called sclerotia. Entering the crown and upper root surface, the fungus

produces a soft, watery rot on the roots. Carrots can become covered with the white growth either in the field or while in storage. If infection occurs in storage, the rot will spread to adjacent roots (33,34).

Bacterial Blight (*Xanthomonas campestris* pv. *carotae*). Plants infected with bacterial blight develop small yellow lesions on leaves surrounded by an irregular halo. The lesions later form irregular brown spots. Root infection may also occur, producing brown or reddish spots. The bacteria can survive in the soil, in seeds, on infected plant debris, or on nearby perennial plants. They can be moved to the host plant in wind-blown or splashed rain, spread through handling of plants, or carried by insects. The bacteria enter the plant through natural openings or wounds. Heavy rain resulting in water soaking favors bacterial invasion. Seed treatment is recommended for control of bacterial blight (33,34).

Cercospora Leaf Spot (caused by *Cercospora carotae*). Cercospora leaf spot is only occasionally seen on carrots in Florida. It is generally not a problem because it is well controlled when growers treat for *Alternaria* (36). The disease initially produces small, round spots with a black center and yellow halo on young leaves. The spots enlarge to form grayish, irregular circles that may fuse into blighted areas. This disease does not affect roots. However, when severe, it can reduce carrot tops enough to hinder effective harvesting. The fungus survives in or on the seed and in old affected leaves. Spores can be carried long distances by the wind. Although water is necessary for the spores to infect leaves, heavy dew provides sufficient moisture. Warm, humid weather favors disease development (10,33,34).

Chemical Control

Growers reported applying a total of 73,000 pounds of fungicides to 93 percent of Florida's carrot acreage in 1996 (22). The most commonly applied fungicides in Florida carrot production are chlorothalonil (Bravo®) and iprodione (Rovral®) (13). Additional products that may be utilized occasionally include copper-based fungicides (Kocide®/ Champion®/Basic Copper), mefenoxam (Ridomil Gold®), metalaxyl (Apron®, and benomyl (Benlate®) (33).

Chlorothalonil (Bravo®). Chlorothalonil is a broad-spectrum nitrile compound fungicide used in carrot production primarily to control Alternaria blight. The median price of chlorothalonil is $8.33 per pound of active ingredient (23). Chlorothalonil may be applied up to 2 days before harvest (PHI=2 days), and the restricted entry interval (REI) under the Worker Protection Standard is 48 hours.

During the years in which usage data has been collected, carrot growers in Florida applied chlorothalonil to an average range of 44 to 99 percent of carrot acreage, an average of 2.9 to 7.6 times annually. Growers used an average rate ranging from 1.17 to 1.29 pounds of active ingredient per acre at each application, with a statewide total ranging from 15,500 to 66,400 pounds of active ingredient annually (13).

Iprodione (Rovral®). Iprodione is a dicarboximide contact fungicide primarily used by Florida carrot growers to control Alternaria blight. The median price of the most commonly used formulation of iprodione on carrots in Florida is $38.50 per pound of active ingredient (23). Iprodione may be applied up to the day of harvest (PHI=0 days), and the restricted entry interval (REI) under the Worker Protection Standard is 12 hours.

During the years in which usage data has been collected, carrot growers in Florida applied iprodione to an average ranging from 19 to 83 percent of carrot acreage. Growers used an average of 1.0 to 1.8 applications annually, with an average rate ranging from 0.83 to 0.97 pounds of active ingredient at each application. Total statewide usage has ranged from 1,800 to 9,400 pounds of active ingredient annually (13).

Cultural Control

Use of disease-free seed is an important preventative measure in the management of pathogens such as *Alternaria*, which can survive on or in seeds (34). Rotating carrots with hosts not affected by the disease-causing pathogen is another valuable cultural control practice for soil-borne pathogens. For example, management of *Sclerotinia* diseases can be aided by rotating carrots with sweet corn, which is not susceptible to the fungus, and

avoiding susceptible crops like lettuce and celery. Additional cultural controls for *Sclerotinia* include turning the soil 6 to 8 inches (15 to20 cm) deep to bury the fungus and any infected plant material, as well as flooding the soil for 6 weeks during the summer (33).

Biological Control

Several organisms parasitize *Rhizoctonia*, including the fungi *Trichoderma*, *Gliocladium* and *Laetisaria* and the nematode *Aphelenchus avenae*. Addition of these biological control agents to infested soil or seeds before planting has been shown to reduce incidence and severity of *Rhizoctonia* diseases in carrots. However, use of biological control agents against soil pathogens is still in the experimental stage and is not presently available as a practical strategy for the commercial grower (34).

Nematode Management

Nematode Pests

When populations of the microscopic worms known as nematodes are high enough to damage carrots, the effect may be severe, particularly in Florida, which produces almost exclusively for the fresh market. Nematodes were not a serious problem while carrot production was centered on the muck soils around Lake Apopka. The short growing season of carrots permits only 1 or 2 generations of nematodes to develop, and the lower soil temperatures during the peak carrot production period are not conducive to nematode activity and damage (38). However, nematode problems are likely to increase as carrot production moves to sandier soils in north Florida.

In sandy soils, both root-knot and sting nematodes are the principal nematode pests of carrot, while in muck soils, root-knot nematodes are the primary concern. In addition to directly reducing yields as a result of root damage, nematodes may also potentially increase the susceptibility of the crop to plant pathogens (39).

Root-knot Nematodes (*Meloidogyne* spp.). Root-knot nematodes are sedentary, internal feeders, entering the root as a second-stage juvenile. Secretion of saliva from the nematode during feeding stimulates enlargement of the surrounding plant cells. Still within the root, the adult female swells to the characteristic pear shape and lays eggs either inside or outside the root tissue. Root-knot nematodes complete their life cycle in 25 days at 27 °C (80 °F). They are most commonly found at a soil depth of between 5 and 25 centimeters (2-10 inches) and can be spread in water or soil. In carrots, infection by root-knot nematodes can result in excessive root production, with the formation of a bushy clump and malformation of the developing carrot. Yield losses may be heavy when plants are infected at the seedling stage. Carrot crops planted in muck soils in the early fall may experience severe damage unless the fields have been flooded during the summer (34,39). With the shift in production to the sandy soils of north Florida, root-knot nematodes are likely to become a greater problem in carrot production.

Sting Nematodes (*Belonolaimus* species). Sting nematodes feed externally, at or near the root tip, and inject a toxin into the root while feeding. They are confined to very sandy soils and have not therefore been a major problem for the carrot production that occurs in the muck soils of Florida. However, as carrot production moves to inorganic mineral soils, sting nematodes could become a major pest. Population growth of sting nematodes is favored by conditions of constant soil moisture (39).

Chemical Control

Available nematicides include the fumigant 1,3-dichloropropene (Telone® II and C-17), which is most effective in sandy soils, and oxamyl (Vydate), which can be applied as an in-furrow treatment or broadcast. Oxamyl cannot be used in all areas because of groudwater contamination (39). Significant use of nematicides for Florida carrot production has not been reported. However, chemical usage data in carrots has not been collected since the shift in production to north Florida. Telone® II and C-17 have been used in some of the newer north Florida production areas during the 1998-1999 growing season (10).

Cultural Control

The most important cultural control for nematodes has historically been pre-plant flooding, in which growers flood and dry fields during the summer prior to fall planting (39). Some growers in the Everglades area rotate carrots with rice, which provides nematode control as a result of flooding the rice fields (5). Crop rotations are expected to be practiced in the newer production regions to suppress nematode populations (10). Additional cultural control practices include destruction of crop residues and weeds (39).

Agricultural Research Service scientists are currently working on developing carrots resistant to a key species of root-knot nematode. Preliminary field tests of crosses between commercial varieties and root-knot nematode resistant germplasm from a wild Brazilian carrot have been encouraging (40).

Biological Control

There are several organisms recognized as antagonists of plant-parasitic nematodes, including certain predatory nematodes, nematode-trapping fungi, and a bacterium (*Pasteuria penetrans*). Nevertheless, the research effort required to develop a practical management strategy utilizing any of these organisms has historically been insufficient. Recent research efforts in Florida suggest that the bacteria *Pasteuria* spp. have potential to suppress populations of important plant-parasitic nematodes in the field. However, efficient techniques for mass rearing of the bacterial spores have not yet been developed. Commercial development is therefore not likely in the near future (41).

Weed Management

Weed Pests

Weed management is an important component of carrot production in Florida. Carrots do not compete well with weeds, which can cause problems at all growth stages. Weeds can reduce carrot size by competing for space, water and nutrients. Early in the season, management of weeds is important to ensure straight growth of carrot roots, since yields can be reduced if weed presence results in deformed carrot root growth. Later in the season, weeds may also interfere with harvest. A number of broadleaf weeds, grasses and sedges may be present during carrot production, and a few are described below (12).

Nutsedge (*Cyperus* species). While annual sedges have been a greater problem on the organic, muck soils previously used for carrot production in Florida, the perennial nutsedges comprise the most important weed group in carrot production on sandy soils (8,25). Yellow nutsedge, common throughout Florida, is tolerant of high soil moisture but not of shade. Purple nutsedge grows well over a range of soil types, soil moisture, and pH, and it can withstand very high temperatures. During adverse conditions, it reproduces from tubers, making it difficult to control (26).

Pigweed (*Amaranthus* species). Several species of pigweed (amaranths) are common weeds in Florida, including smooth pigweed (*Amaranthus hybridus*), spiny amaranth (*Amaranthus spinosus*) and livid amaranth (*Amaranthus lividus*) (25). Pigweeds are summer annuals with taproots. These broadleaf plants reproduce by seed and can reach heights of 2 meters (27). Researchers have found short pigweed seedlings to be susceptible to mole cricket damage, and pigweeds may therefore serve as alternative food sources on which mole cricket populations may develop before moving to vegetable crops (28).

Lambsquarters (*Chenopodium album*). Lambsquarters is a summer annual broadleaf that does well in all soil types and over a range of soil pH conditions. Reproducing by seed, the plant has a taproot and grows to a maximum of 2 meters (26).

Ragweed (*Ambrosia artemisiifolia*). Ragweed, another important weed in Florida carrot production, is a herbaceous summer annual with a taproot. It reproduces by seed and reaches a height of 0.2 to 2.5 meters. When crushed, its leaves emit a strong odor (27).

Annual Grasses. Annual grasses, such as crabgrass (*Digitaria* spp.), goosegrass (*Eleusine indica*) and fall panicum (*Panicum dichotomiflorum*) can also be a problem for carrot growers in Florida. Crabgrass roots at the nodes and reproduces by seed,

flowering from June to October. Goosegrass, also a summer annual that flowers from July to October, is similar in appearance to crabgrass but grows in tufts and does not root at the nodes. Fall panicum has stems that branch extensively and flowers from July to September. Fluazifop-p-butyl is the principal herbicide used to control annual grasses in Florida carrot production (8,29,30).

Chemical Control

Ninety-two percent of Florida's treated carrot acreage received herbicide applications in 1996, with a total of 10,300 pounds of active ingredient applied (22). The most common herbicides used on carrots in Florida are Linuron (Lorox®/Linex®) and fluazifop-p-butyl (Fusilade®). Less commonly used are glyphosate (Roundup®), metribuzin (Sencor®), paraquat (Gramaxone®), sethoxydim (Poast®) and trifluralin (Treflan®) (11,13).

Linuron (Lorox®/Linex®). Linuron is a substituted urea herbicide used both pre- and post-emergence to control annual and perennial broadleaf and grassy weeds. It is the only pre-emergence herbicide available for carrots in Florida. Growers may make one pre-emergence application of linuron and additional post-emergence applications, up to 4 pounds per acre per season. The projected approximate price of linuron in Florida during 1999 is $13.20 per pound of active ingredient (31). Linuron may be applied up to 14 days before harvest (PHI=14 days), and the restricted entry interval (REI) under the Worker Protection Standard is 24 hours.

During the years in which usage data has been collected, carrot growers in Florida have applied linuron to a range of 86 to 92 percent of treated acres, an average of 3.0 to 5.0 times annually. Growers applied an average ranging from 0.30 to 0.64 pounds of active ingredient per treated acre at each application, with a state-wide annual total ranging from 9,400 to 17,900 pounds of active ingredient (13). One grower recently reported linuron applications to 100 percent of carrot acreage, in one pre-emergence treatment and an average of 1.5 times per crop in post-emergence treatments (8).

Fluazifop-p-butyl (Fusilade®). Fluazifop-p-butyl is a selective phenoxy herbicide used post-emergence to control annual and perennial grasses. Fields should not be flooded within 45 to 60 days of application, and Palm Beach and Hendry counties require a 60-day interval before flooding. The projected approximate price of fluazifop-p-butyl in Florida during 1999 is $71.05 per pound of active ingredient (31). Fluazifop-p-butyl may be applied up to 45 days before harvest (PHI=45 days), and the restricted entry interval (REI) under the Worker Protection Standard is 12 hours.

During the years in which usage data has been collected, carrot growers in Florida have applied fluazifop-p-butyl to a range of 41 to 81 percent of treated acres, an average of 1.0 to 1.8 times annually. Growers used an average ranging from 0.09 to 0.12 pounds of active ingredient per treated acre at each application, with the annual state total ranging from 400 to 900 pounds of active ingredient (13). One grower recently reported fluazifop-p-butyl applications of one time per crop to 50 to 70 percent of carrot acreage (8).

Cultural Control

Mechanical cultivation to control weeds is not generally practiced in Florida carrot production, because cultivation can damage young storage roots, producing culls (7). On organic soils with high water tables it is feasible to use flooding during the fallow season to reduce the weed seeds and vegetative growth for the following season (10). However, with the shift in production to inorganic soils, fewer growers are now able to practice fallow flooding.

Important cultural controls of weeds in Florida include following appropriate management practices such as fertility and water management, as well as optimum plant populations, to give the crop as much of a competitive advantage over the weeds as possible. Additionally, prevention by controlling weeds in fence rows and ditch banks and proper cleaning of equipment can aid in the overall weed management program (32)

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