CIR 1235

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Florida Crop/Pest Management Profiles: Celery[1]

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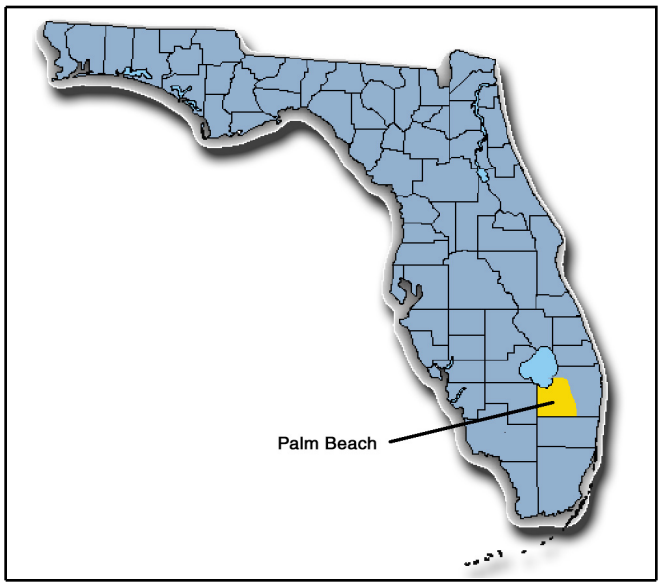
Production Facts

Celery production in Florida has consistently been the second highest, after California, even accounting for recent reductions in Florida acreage. From 2004 to 2007, Florida celery acreage was approximately three thousand acres (1). In 1992, the last year for which data were collected on celery production in Florida, 8,000 acres were planted and 7,600 acres were harvested, with total production of 315.4 million pounds. Average yield for Florida celery in that year was 41,500 pounds per acre, and the crop had a total value of $39.1 million (2). Nearly the entire Florida crop of celery is produced for the fresh market as full stalks or celery hearts. Several hundred acres are produced for canned celery, as well as prepared as fresh celery sticks and fresh diced and crescent celery (1).

Production Regions

Presently, the only celery-producing region in Florida is the Everglades region (around the southern tip of Lake Okeechobee in Palm Beach County) (1).



Major Celery Production Region in Florida.

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Production Practices

Celery is a biennial plant, which produces vegetative growth (the edible stalks, or petioles) during the first year and seed stalks during the second year. It is harvested about 90 days after transplanting, but if the plant were left to grow for the second year and were exposed to low temperatures, it would produce a longer stem and a seed head (3).

Celery in Florida is grown on organic, muck soils. Soil preparation is more important for celery than for most other crops. Fields in which celery is to be planted are plowed, disced and leveled, then alternately flooded and dried during the summer months to manage nematodes, soil-borne diseases and insects. After flooding, the fields are plowed, disced and leveled again, followed by a sub-soiling mole-draining operation to aid in sub-surface irrigation, and finally, the fields are fertilized before planting (4).

Celery requires a long, cool growing season and is sensitive to both high and low temperatures. The optimum temperature for growth is between 60 and 70°F (15.6 to 21.1C), with a maximum monthly average of 70 to 75°F (21.1 to 23.9°C). Under high temperatures and moist conditions, the crop is more susceptible to disease and insect damage, as well as physiological problems. If temperatures drop below 50°F (10°C) for 10 to 14 days when plants are young, bolting may occur, during which the plant enters the seed-producing stage of the second year during its first year. If that occurs, growth slows and initiation of flower stalks occurs prematurely as the plant approaches marketable size, leaving a stalk with no commercial value. The temperature requirements of celery limit commercial production in the winter months to California, Florida and south Texas. In addition, timing of planting is essential for producing healthy transplants and bringing the crop to harvest without slowing its growth, which can result in poor market quality (4).

Celery is usually planted in south Florida between October and March. Among the varieties common in the state are Floribelle-M9, June Belle and Florida 683. Seedlings for transplant are grown in greenhouses in the central part of the state. After 3 months in the greenhouse, celery is transplanted to the field, using mechanical transplanters, where it remains for an additional three months. Plants are set at 18 to 40 inches (46 to 102 cm) between rows and 6 to 12 inches (15 to 30 cm) between plants, giving a plant population under closest spacing of 58,080 per acre (1,3,4).

One hundred percent of celery acreage in Florida is irrigated. The plant is sensitive to a fluctuating supply of water because of its shallow roots, but excessive water at the roots can also slow growth. The crop therefore requires more frequent irrigation. Overhead sprinklers are used to irrigate celery in Florida only following transplanting. Once transplants have recovered from the shock, irrigation is limited to sub-surface infiltration. All celery in Florida is grown where the producer can regulate the sub-surface water table by manipulating a series of ditches and canals. The canals within this sub-surface irrigation system also allow for rapid drainage after heavy rains (1,3,4).

Celery in Florida is harvested from early December to late May. Once celery reaches marketable size, it must be harvested within 6 to 8 days or reduction in quality will make it unmarketable. Celery growers therefore schedule planting so that a uniform quantity of celery is ready to harvest every week (3).

Worker Activities

Celery in Florida is harvested by hand, where crews cut, trim, size, wash and pack the crop in the field. Outer petioles (stalks) are removed, the celery is trimmed to a uniform length, which is usually 14 or 15 inches (36 to 38 cm), and it is packed into cartons or crates. After leaving the field, the packed celery is taken to a cooling facility, where it is hydrocooled and then packed onto refrigerated trucks and transported to the market. Celery that will be used as sticks, diced, or crescents may be machine harvested. It is taken to a packinghouse, where it is washed and processed. After cooling, it is loaded onto trucks for transport (4).

The most common unit in which shipments are recorded for celery is the crate, which has a billing weight of 60 pounds and an actual net weight that can

range from 55 to 75 pounds. Celery is sized by the number of dozen or half dozen stalks fitting into the standard packing crate, with a smaller sizing therefore given to larger celery. Trimmings and outer petioles are often used for processing, in soups, juices and convenience dinners. When the large outer stalks are stripped to sell the remainder as celery hearts, the outer stalks are processed. Much of Florida's celery production, that which is sized at 4 or 6 dozen stalks per box or smaller, is sold as hearts. The hearts are washed thoroughly, stripped of suckers, leaves and damaged petioles, cut to 8 to 10 inches (20 to 25 cm) in length, and packaged in polyethylene bags, with 2 to 3 hearts per bag. Any celery sold for processing is washed and cut up before leaving for the processor. Fresh celery is primarily sold to retailer-wholesalers, terminal market brokers, wholesale handlers and the military (1,4).

Insect/Mite Management

Insect/Mite Pests

The most important insect and related pests of celery in Florida are serpentine leafminers (*Liriomyza trifolii*) and a worm complex, consisting of armyworms [mainly beet armyworm (*Spodoptera exigua*) and to a lesser extent fall armyworm (*Spodoptera frugiperda*) and southern armyworm (*Spodoptera eridania*)], cutworms [mainly granulate cutworm (*Feltia subterranea*) and occasionally black cutworm (*Agrotis ipsilon*)], and occasionally cabbage looper (*Trichoplusia ni*) and the green celeryworm (*Platysenta sutor*). Wireworms [corn wireworm (*Melanotus communis*), southern potato wireworm (*Conoderus falli*) and tobacco wireworm (*Conoderus vespertinus*)], aphids [mainly green peach aphid (*Myzus persicae*) and melon aphid (*Aphis gossypii*) and occasionally green citrus aphid (*Aphis citricola*) and rice root aphid (*Rhopalosiphum rufiabdominalis*)] and twospotted spider mites (*Tetranychus urticae*) are minor or occasional pests. The celery leaftier, celery webworm, saltmarsh caterpillar, celery and soybean loopers, celery caterpillar, banded cucumber beetle, aster leafhopper, tarnished plant bug, garden fleahopper, potato flea beetle, southern green stinkbug, silverleaf and sweet potato whiteflies, and onion and tobacco thrips may occasionally be seen on celery, but currently are not economically damaging (5,6).

AMERICAN SERPENTINE LEAFMINER (*Liriomyza trifolii*). The serpentine leafminer *Liriomyza trifolii* has historically been one of the most serious pests of celery in Florida. Its host range is very broad, including many vegetable crops and weeds. Vegetable hosts, in addition to celery, include spinach (*Spinicia oleraceae*), lettuce (*Lactuca sativa)*, muskmelon (*Cucumis melo*), cucumber (*Cucumis sativus*), pumpkin (*Cucurbita pepo*), okra (*Hibiscus esculentatus*), pepper (*Capsicum* sp.), tomato (*Lycopersicon esculentum*), eggplant (*Solanum melongena*), potato (*Solanum tuberosum*), and carrot (*Daucus carota* var. *sativae*). Weed species serving as hosts to the serpentine leafminer in Florida include lambsquarters (*Chenopodium album*), cocklebur (*Xanthium* sp.), black nightshade (*Solanum nigrum*), Spanish needle (*Bidens pilosa*), hairy galinsoga (*Galinsoga ciliata*), and sowthistle (*Sonchus* spp.) (7,8).

Leafminer attack on celery can result in early senescence of outer petioles, longer time to maturity, and a reduction in yield, although celery plants in south Florida have been shown to withstand substantial leafminer damage without a reduction in growth or yield. Of greater concern to celery growers is the effect of leafminer feeding on cosmetic quality. Celery plants with insect damage on more than 2 petioles receive a lower grade, according to USDA standards. Protecting celery plants from leafminer damage during the last month of the growing season has been shown to be the key to preventing cosmetic damage to celery in south Florida. During the first two months after transplanting, leafminer populations below 60 pupae per 20 leaflets held for 7 days is acceptable. However, during the final month in the field, leafminer densities as low as 3 pupae per 20 leaflets can result in a significant loss in quality (9,10).

Adult leafminers feed at flowers. In addition, adult females puncture celery leaves with their ovipositors (egg-laying organs) and feed on the plant juices that accumulate at the feeding puncture. Males cannot puncture the leaf, so they feed after females have left. The female inserts an egg between the upper and lower epidermis (leaf surface), and the larva feeds within the leaf. As the larva feeds, it moves throughout the leaf from within, creating a

mine in an irregular line (serpentine mine). The mine increases in diameter as the larva grows and consumes greater amounts of leaf tissue. When fully grown, the larva cuts through the upper leaf surface and leaves the leaf to pupate, falling between the petioles or onto the soil. The larva usually exits the leaf during the morning hours and becomes a pupa by mid-afternoon. After completing the pupal stage, the leafminer emerges from the soil or plant debris as an adult (9).

Although leafminers are more abundant during the middle and late part of the season, they can be a problem at any time. The time required for *L. trifolii* to complete its development on celery in the laboratory has been shown to vary from 14 days at 35°C (95°F) to 64 days at 15°C (59°°F). Survival of pupae is very low at 35°C, however, and reduced egg laying occurs at 15°C. Optimum temperature for survival and egg laying has been demonstrated to be 30°C (86°F). Based on these studies of survival and egg laying at different temperatures, *L. trifolii* is expected to experience maximum population growth between May and October in central Florida (when average air temperatures are at least 25°C or 77°F), lower population growth during March, April and November (when average air temperature is about 20°C or 54°F), and virtually no population growth from December to January (when average air temperature is about 15°C or 59°F). Temperatures in south Florida, where celery is now produced exclusively, are higher, allowing for leafminer population growth through most of the year (11).

BEET ARMYWORM (*Spodoptera exigua*). Armyworms are the principal component of a worm complex that affects nearly all crops in south Florida and is one of the greatest insect problems of celery in the state. The worm complex, which also includes cutworms and occasionally cabbage loopers, among others, appears each year first in south Florida and then moves northward. The most important of the armyworms on celery is the beet armyworm, which also feeds on many cultivated and wild plants, including corn, pepper, tomato, potato, onion, pea, sunflower, citrus, soybean and tobacco, as well as plantain and lambsquarters (5,12,13).

The beet armyworm lives in the adult (moth) stage for four to ten days. Each female can lay about 600 eggs (in clusters or egg masses of about 80) within a week, and the eggs hatch in two to three days. Upon emerging, the larvae spin webs around themselves to feed first on the egg mass and later on the plant. The larvae, which at first feed in groups under the silk webbing and later feed alone and cease to produce webs, continue to feed for between one and three weeks. They then construct a loose cocoon with soil and leaf parts, within which they pupate. The adult moth emerges from the cocoon approximately one week later. Since the beet armyworm has a short life cycle (four to five weeks) and survives the winter in south Florida, many generations can occur each year. The long growing season in south Florida and the wide host range of this insect allow it to maintain an active presence all year round in that region, providing a reservoir for yearly migration into north Florida and the southeastern U.S. Pheromone trap data collected in south Florida indicate that beet armyworm adults are usually most prevalent during the months of May and June, although they are collected in all months (5,12,13).

GRANULATE CUTWORM (*Feltia subterranea*). Cutworms are another part of the worm complex that attacks celery every year in Florida. Although the black cutworm (*Agrotis ipsilon*) may be present, the granulate cutworm is a greater problem in celery in Florida. These cutworms attack many field and other vegetable crops, including beans, crucifers, cucurbits, corn, cowpea, lettuce, onion, pea, pepper, potato, spinach, sweet potato and tomato. Cutworm larvae become active in the spring, hiding within the soil during the day and feeding on young plants at night. They can cut off plant stems near soil level, and they feed on the leaves, chewing into the developing petioles of celery. Cutworm larvae continue to feed until mature (about three to four weeks), then pupate within the soil. After two to four weeks, the adult moths emerge and the adult females begin to lay clusters of eggs during the night on the lower surface of host plant leaves. Eggs hatch within three to five days, and young larvae feed on the leaves, retreating to the base of the plants as they get older (5,6).

CABBAGE LOOPER (*Trichoplusia ni*). The cabbage looper occasionally forms part of the worm complex on celery in Florida. It has a broad host range, including cabbage and related crucifers, lettuce, celery, parsley, tomato, potato, spinach, soybean and cotton. In Florida, cabbage loopers overwinter as pupae. In the spring, when the adult moths emerge, each female deposits 275 to 350 eggs on host plant leaves. Within several days, the larvae (caterpillars) emerge and begin to feed. After feeding for two to four weeks, they pupate within cocoons on the leaves. Within two weeks, the adult moths emerge. Several generations of the cabbage looper occur each year in Florida. In south Florida, pheromone trapping data show adult populations to be highest during the late spring and summer months, and in some years in the late fall (5).

WIREWORMS (Family Elateridae). Wireworms can damage celery in south Florida, but they are generally not a problem, as long as growers are able to practice off-season flooding, which effectively controls them. The hard, slender wireworms, which are the immature stage (larvae) of click beetles, can be found throughout the root zone, feeding on underground plant parts. Symptoms of wireworm attack may include a sudden reduction in plant stand. Injury from wireworms can also leave the plant more susceptible to secondary infection from soil-borne plant pathogens. Whether chemical or cultural, control of wireworms must be preventive (5,13).

The corn wireworm, *Melanotus communis*, is the most damaging wireworm on celery and other vegetable crops grown on the organic, muck soils of south Florida (6). Attacking mainly corn and small grains, it also feeds on the roots, seeds and tubers of many flower and vegetable crops. The life cycle of this wireworm may last from three to six years. Adults deposit eggs on the roots of grass hosts in May or June, and emerging larvae feed and develop throughout the summer, then overwinter in the soil during the first year. Most remain as larvae for five years and pupate within cells in the soil during the summer of the 6th year. Adults emerge in about 18 days and feed on pollen. The following May or June, they become active and deposit eggs (5,13).

The southern potato wireworm (*Conoderus falli*) prefers potato tubers but will also damage most crops, including celery, sweet potatoes, carrots, and corn roots, as well as low-lying fruit of strawberries, cantaloupes, watermelons and tomatoes. On crops in which it damages roots, the wireworm chews holes, with a single root sometimes having more than ten holes. The southern potato wireworm has developed resistance to chlorinated hydrocarbons and organophosphate insecticides (5,13).

APHIDS (Family Aphididae). Aphids are usually a minor pest on celery in Florida, but they may be of concern because of their role as virus vectors. To manage them, growers try to use compounds that preserve beneficials (predators and parasites) when possible, but non-selective compounds may be used when there is a large aphid outbreak. The most important aphids in Florida celery are the green peach aphid (*Myzus persicae*) and the melon aphid (*Aphis gossypii*). The green citrus aphid (*Aphis spiraecola*) may also colonize celery in Florida (5).

Aphids feed by inserting their needle-like mouthparts into plant tissue and sucking up plant juices. In addition to depleting the plant of nutrients, they can inject toxins that produce abnormal plant growth. While feeding, they also excrete large amounts of a sweet, sticky liquid called honeydew, on which black sooty mold often grows. Throughout Florida, aphid populations are exclusively female and are able to reproduce abundantly. The immature nymphs feed as well, and within just a few days they mature and begin producing more young. As a result of this rapid reproduction, aphid populations can increase dramatically. When populations are high, winged aphids are produced, which fly to new plants. Despite the potential for rapid increase in population, control of aphids is not difficult. Since they remain on the exterior of the plant and do not lay eggs, all stages are susceptible. When applying insecticides, complete coverage is necessary, since aphids tend to be more numerous on the underside of leaves and in protected areas of the plant. In addition, there are several natural enemies that help to maintain aphid populations at low levels (5).

The green peach aphid (*Myzus persicae*), in addition to feeding on celery, also colonizes a wide range of plants, including cabbage and related crucifers, parsley, turnip, lettuce, chard, endive, tomato, potato, pepper, beets, spinach, and mustard greens. It is one of the most important aphid virus vectors and can transmit over 100 plant viruses, including those that affect celery in Florida (cucumber mosaic virus and celery mosaic virus). The green peach aphid has developed resistance to a great number of insecticides (14).

The melon aphid (*Aphis gossypii*) is also a vector of both celery viruses in Florida. It has a broad host range as well and can colonize beans, cowpea, citrus, cucurbits, eggplant, peppers, potato, tomato, spinach, okra, beets, cotton, and many ornamental plants, as well as having many weed hosts. Many overlapping generations occur each year (14).

TWOSPOTTED SPIDER MITE (*Tetranychus urticae*). Twospotted spider mites are a minor and occasional pest of celery in Florida. They are more of a problem later in the season, when their presence on the harvested product is undesirable. They are known to have over 180 host plants, including at least 100 crop plants. Symptoms of spider mite damage begin with a bronzed appearance on leaves and include yellow and reddish-brown blotches on both leaf surfaces. Under severe infestations, paling and dropping of leaves may occur. Spider mites are nearly microscopic, but a powdery appearance on leaves from their molted skins indicates their presence. In addition, twospotted spider mites spin silken webs on leaf surfaces. They feed by piercing the leaf surface (epidermis) with their long, slender mouthparts and withdrawing plant sap (5,6).

Hot, dry weather speeds spider mite development, and populations may increase rapidly under optimum conditions. Each female may produce up to 19 eggs per day and a total of up to 100 eggs. The larvae hatch after 6 to 19 days and begin to feed. Mites experience a resting period after the larval stage, then pass through two nymphal stages, with another resting period after each one. Maturity into adults may take as few as five days or as many as 20 days, depending on the temperature. The age structure of the population should be determined when considering the use of chemical controls. When many nymphs are present, the population is probably increasing, whereas if many adults are present, particularly males, it is probably declining. In addition, if a miticide is used, a second application is necessary in Florida between five and seven days after the first. The second application kills the mites that as eggs escaped the first application. Timing is critical to prevent those mites from maturing and laying eggs (5,6).

Chemical Control

Acephate (Orthene®), cyromazine (Trigard®), abamectin (Agri-Mek®), and pymetrozine (Fulfill®) are the insecticides used most often in Florida celery production. Spinosad (Spintor®) and zeta-cypermethrin (Mustang Max®) are applied occasionally. Acetamiprid (Assail®), azadirachtin, B.t., carbaryl (Sevin®), cyfluthrin (Baythroid®), dimethoate, dinotefuran (Venom®), emamectin (Proclaim®), endosulfan (Thiodan®), imidacloprid (Admire®), malathion, methomyl (Lannate®), methoxyfenozide (Intrepid®), naled (Dibrom®), oxamyl (Vydate®), insecticidal oils (Sun Spray®), insecticidal soap (M-Pede®), permethrin, pyrethrins plus piperonyl butoxide (Pyrenone®), pyrethrins plus rotenone (Pyrellin®), spiromesifen (Oberon®), and tebufenozide (Confirm®) are also available for use on celery in Florida (5). Methoprene (Extinguish®) is available for fire ant treatment.

CYROMAZINE. Cyromazine is a triazine insecticide that works as an insect growth regulator. It is one of the two principal insecticides applied to celery for the management of leafminers. Cyromazine, which has no effect on the adult leafminer, is applied as a foliar spray. The price of cyromazine is approximately $188 per pound of active ingredient, and the average cost per application between 2004 and 2007 in Florida was $23 per acre (15). Cyromazine may be applied up to seven days before harvest (PHI=7 days), and the restricted entry interval (REI) under the Worker Protection Standard is 12 hours.

Between 2004 and 2007, cyromazine was applied 2 to 3 times per crop. During these years, average application rates have ranged from 0.12 to 0.13 pounds of active ingredient per acre, and total

statewide annual usage has ranged from 520 to 1,100 pounds of active ingredient (15).

ABAMECTIN. Abamectin is a fermentation product composed of two avermectins derived from the soil bacterium *Streptomyces avermitilis*. Florida celery growers apply this restricted-use miticide/insecticide as a foliar spray to manage *Liriomyza* leafminers and twospotted spider mites. The price of abamectin is approximately $4,570 per pound of active ingredient, and the average cost per application between 2005 and 2007 in Florida was $42 per acre (15). Abamectin may be applied up to seven days before harvest (PHI=7 days), and the REI under the Worker Protection Standard is 12 hours.

Between 2005 and 2007, abamectin was applied 1 to 2 times per crop. During these years, the application rate has been 0.009 pounds of active ingredient per acre, and total statewide annual usage has ranged from 16 to 67 pounds of active ingredient (15).

ACEPHATE. Acephate is an organophosphate insecticide used in the management of beet and fall armyworm, green peach aphid, and cabbage loopers. The price of acephate is approximately $14 per pound of active ingredient, and the average cost per application between 2004 and 2007 was $12 per acre (15). Acephate may be applied up to 21 days before harvest (PHI= 21 days), and the REI under the Worker Protection Standard is 24 hours.

Between 2004 and 2007, acephate was applied to once a crop to 40 to 50 percent of celery acreage in Florida. During these years, average application rates have ranged from 0.75 to 0.92 pounds of active ingredient per acre, and total statewide annual usage has ranged from 1,000 to 1,620 pounds of active ingredient (15).

PYMETROZINE. Pymetrozine is an insecticide which causes novel feeding cessation among certain sucking insects. Florida celery growers apply this insecticide as a foliar spray to manage aphids. The price of pymetrozine is approximately $174 per pound of active ingredient, and the average cost per application between 2005 and 2007 in Florida was $16 per acre (15). Pymetrozine may be applied up to seven days before harvest (PHI=7 days), and the REI under the Worker Protection Standard is 12 hours.

Between 2005 and 2007, pymetrozine use has been steadily increasing, rising from use in 25 percent of the crop in 2005 to 40 percent of the acreage in 2007. During these years, the application rate has been between 0.008 and 0.011 pounds of active ingredient per acre, and total statewide annual usage has ranged from 40 to 90 pounds of active ingredient (15).

SPINOSAD. Spinosad is another fermentation product composed of two spinosyns derived from the soil actinomycete *Saccharopolyspora spinosa*. Florida celery growers apply this insecticide as a foliar spray to manage *Liriomyza* leafminers and caterpillars. The price of spinosad is approximately $263 per pound of active ingredient, and the average cost per application in 2005 in Florida was $42 per acre (15). Spinosad may be applied up to one day before harvest (PHI=1 day), and the REI under the Worker Protection Standard is four hours. In 2005, spinosad was applied to two-thirds of the celery acreage in Florida. During this year, the application rate was 0.16 pounds of active ingredient per acre, and total statewide annual usage was 314 pounds of active ingredient (15).

Zeta-CYPERPERMETHRIN. This is a broad-spectrum, restricted-use synthetic pyrethroid insecticide used by Florida celery growers primarily for the management of armyworms, cabbage loopers, and black and granulate cutworms, although it can also be used to manage vegetable leafminers, green cloverworm, and leafhoppers. The price of zeta-cypermethrin is approximately $67 per pound of active ingredient, and the average cost per application in 2005 in Florida was $4 per acre (15). Zeta-cypermethrin may be applied up to one day before harvest (PHI=1 day), and the REI under the Worker Protection Standard is 12 hours.

In 2005, zeta-cypermethrin was applied to three-quarters of celery acreage in Florida. During this year, the application rate was 0.06 pounds of active ingredient per acre, and total statewide annual usage was 127 pounds of active ingredient (15).

Use of Chemicals in IPM Programs

Celery growers in Florida are aware of the importance of beneficial insects and try to use chemicals that are least damaging to natural populations of beneficials. For leafminers, they apply primarily cyromazine and abamectin, and for lepidopteran larvae (worm complex) they apply *Bacillus thuringiensis* when possible, in an effort to minimize adverse effects on natural enemies.

For several years, the Everglades Research and Education Center at Belle Glade, Florida has been monitoring moth activity of several lepidopterous pests through the use of pheromone traps. Data are maintained on beet armyworm activity throughout the year and are available to growers and scouts to aid in forecasting populations of these pests.

Use of Chemicals in Resistance Management Programs

Reductions in effectiveness of insecticides used to control the leafminer *Liriomyza trifolii* have been reported since the 1950's, and the resistance problem has severely limited options for management of the leafminer. Parathion, diazinon, naled, azinphos-methyl, dimethoate, and oxamyl had all lost effectiveness against the leafminer by the late 1970's. By 1976, no insecticide labeled for use on celery was able to control leafminer populations in Florida, and after permethrin was made available in 1978, it became ineffective within two years. Effective chemical control for the leafminer in Florida was not available until 1982, with the introduction of cyromazine. However, by 1989, cyromazine resistance in the leafminer had been confirmed in the Everglades area. The leafminer strain resistant to cyromazine was found not to be resistant to abamectin. Beginning in 1990, Section 18 exemptions were granted for the use of abamectin on celery in Florida within a controlled insecticide rotation to manage resistance (16).

A program was developed for celery growers to manage cyromazine resistance in *Liriomyza trifolii* by following several insecticide management and crop management guidelines. Within the program guidelines, 1.) the number of insecticide applications was to be limited by using thresholds to determine the need for sprays; 2.) early control was to be maximized by beginning the spray program with abamectin; 3.) each two sprays of abamectin were to be rotated with two sprays of cyromazine; 4.) each crop cycle was to be completed with two sprays of abamectin to minimize the number of adults leaving the soil after the harvest; and 5.) the use of pyrethroids (specifically permethrin and esfenvalerate) was to be avoided to minimize the effects on natural enemy populations. The program recommended not using cyromazine during the summer months, when celery acreage in the field is low, in order to allow for immigration and reproduction of leafminers susceptible to the insecticide (39). Abamectin is now labeled for use on celery, and growers continue to alternate cyromazine with abamectin, despite the large difference in cost, in an effort to manage resistance in the leafminer. This alternation of the two insecticides is the most important aspect of the resistance management program.

Cultural Control

Flooding celery fields for at least one month in the summer is an effective control for wireworms. Celery growers in south Florida regularly practice summer flooding as a means of managing not only soil insects, but nematodes and diseases as well (13).

Biological Control

Leafminers. Hymenopterous parasitoids that have been collected from *Liriomyza trifolii* on celery include *Opius dimidiatus*, *Diglyphus intermedius*, *Chrysonotomyia* sp., *Diglyphus pulchripes*, *Mirzagrammosoma lineaticeps*, *Closterocerus cinctipennis*, *Chrysocharis* spp., *Derostenus agromyzae*, *Derostenus variipes*, *Achrysocharella formosa*, *Halticoptera patellana*, and *Halticoptera circulus*. The most common parasitoids of leafminers on celery in Florida are *O. dimidiatus*, *D. intermedius*, and *Chrysonotomyia* sp., which are able to parasitize greater than 90 percent of active mines in unsprayed celery or nearby weeds. However, percentage of parasitism can vary greatly, depending on population levels, crop age, cropping season, location, pesticide treatments, and spray drift. Populations of these

parasites are able to increase at least as fast as the leafminer populations (17).

The importance of natural control of the serpentine leafminer by parasites and the disruption of that control by the use of insecticides highly toxic to the parasites has been recognized for decades. Leafminers did not become a problem on celery in Florida until the use of chlorinated hydrocarbons in the 1950's killed the parasites with little effect on the leafminers, thereby increasing leafminer populations considerably.

Researchers at that time recognized that parasite populations could be maintained by the adequate management of less toxic insecticides with short residual activity. Furthermore, the insect's habit of mining within the leaf as a larva allows it to escape contact with insecticides during a significant part of its life cycle. Therefore, any chemical control of leafminer populations requires the simultaneous preservation of parasite populations, and celery growers in Florida have been attempting to preserve leafminer natural enemies for two decades. In addition to choosing less toxic insecticides targeting leafminers, growers also manage caterpillars (armyworms, cutworms, loopers) with leafminer management in mind. For example, they choose *Bacillus thuringiensis* when possible to manage caterpillars instead of a more non-selective insecticide, which knocks down populations of leafminer parasites (18).

Disease Management

Disease Pathogens

The most important diseases affecting celery in Florida are early blight (caused by *Cercospora apii*), bacterial blight and brown stem (caused by *Pseudomonas cichori*), and Rhizoctonia stalk rot (caused by *Rhizoctonia solani*). Pink rot (caused by *Sclerotinia sclerotiorum*), late blight (caused by *Septoria apii*), and southern blight (caused by *Sclerotium rolfsii*) are occasionally a problem. Damping-off (caused by *Rhizoctonia*, *Pythium*, *Fusarium* and *Sclerotinia* spp.), cucumber mosaic (caused by cucumber mosaic virus), red root (caused by *Fusarium* and *Pythium* spp.) and celery mosaic (caused by celery mosaic virus) are minor diseases on celery in the state (19).

EARLY BLIGHT (caused by *Cercospora apii*). Early blight is the most important disease of celery in Florida. Symptoms first appear as small, circular spots on the leaves or petiole. The spots enlarge rapidly and can combine to form a large, blighted area over entire leaflets or stalks. Spores develop in the center of the spots, becoming numerous under humid conditions. Lesions may therefore appear gray in the center, and in addition, large chlorotic areas may surround them. Florida's high relative humidity, long dew periods and high temperatures present ideal environmental conditions for development of the disease. Spore production primarily occurs at night when temperatures are in the range of 58 to 86°F (14.4 to 30°C) for at least ten hours and relative humidity is near 100 percent. Most spores disperse on the wind during the morning hours, as the relative humidity declines. Once spores land on appropriate plants, disease symptoms appear within 12 to 14 days of spore germination and penetration of the plant tissue. Growers primarily apply chlorothalonil, propiconazole, and strobilurin compounds to manage early blight. Since many air-borne spores are released during the harvest of celery, any fields within one-half mile downwind should be protected with a fungicide during the harvest operation (19,20).

BACTERIAL BLIGHT (caused by *Pseudomonas cichorii*). Bacterial blight is also one of the principal diseases of celery in Florida. Bacterial blight lesions are very similar to lesions caused by the early blight fungus (*Cercospora apii*), but are smaller, with a deeper red color and have a more water-soaked appearance. The margin of the lesion produced is also clearer than that of early blight, and chlorosis occurs more slowly. The disease is favored by warm and humid conditions and is difficult to control when rains are frequent. The bacteria can be spread from plant to plant by rain, irrigation, or on machinery and people. Symptoms appear within days of the bacteria entering a plant's tissue through natural openings or wounds. A preventive spray program aids in management of bacterial blight, and growers principally utilize copper compounds in preventive sprays. However,

strains tolerant to copper fungicides have been reported in south Florida (19).

BROWN STEM (caused by *P. cichorii*). Brown stem is a petiole necrosis of celery that has been seen in the Everglades Agricultural Area of Florida for nearly 50 years. The pathogen that causes brown stem is the same as that causing bacterial blight. Unlike bacterial blight, which is present every year, brown stem is more sporadic, appearing approximately every five or six years. When it does occur, however, it can be severely damaging to the celery crop. The worst outbreak occurred during the 1992-93 winter season in the Everglades area, resulting in estimated losses to celery producers of $5 million. During that outbreak, the disease was found in 100 percent of surveyed celery fields, and the average incidence was approximately five percent (21).

Brown stem causes more curling and stalk rot than bacterial blight. The principal symptom of brown stem is a brown discoloration over the entire petiole. Although brown streaks may be seen along the whole petiole, the base of the stalk receives the greatest amount of damage. Symptoms intensify closer to harvest, as the plant approaches maturity. The reason for the sporadic nature of the disease is unknown, and the link between outbreaks of brown stem and specific weather conditions is still under investigation (21).

LATE BLIGHT (caused by *Septoria apii*). Late blight is only occasionally a problem in the Everglades area. The disease is favored by cool, wet conditions, including temperatures of 50 to 81°F (10 to 27°C). The principal symptom of late blight is the appearance of lesions containing small black fruiting bodies (pycnidia). The spores produced within the pycnidia can be dispersed by rain, machinery, or people, but infected seed is the primary source of inoculum. The pycnidia become non-viable after two years, and celery growers manage the disease well by using seed that is older than two years. Outbreaks may occur when seed is in short supply and green seed must be used. When the disease becomes a problem, growers apply strobilurin compounds (20).

RHIZOCTONIA STALK ROT (caused by *Rhizoctonia solani*). Rhizoctonia stalk rot can be a significant problem for celery growers in Florida, particularly under warm and wet conditions. The stalks at the base of the plant develop sunken, red lesions as a result of infection by the stalk rot pathogen. When infection is severe, extreme stripping of the stalks may be necessary. Rhizoctonia rot can develop over a broad range of soil conditions, including a range of soil temperatures, soil pH, soil type, soil moisture, and fertilizer level. Celery transplant beds are flooded and fumigated with methyl bromide to manage both Rhizoctonia rot and nematodes (19).

PINK ROT (caused by *Sclerotinia sclerotiorum*). Pink rot is only occasionally a problem in Florida. Under conditions of drought when growers are unable to flood fields in the summer, populations of the fungus can build up in the soil, resulting in an outbreak during the celery growing season. When outbreaks occur, celery plants in the field can suddenly wilt and collapse. Plant tissue near the soil line usually develops a soft, watery decay, which appears pink and becomes covered with the white, cottony mycelium (body mass) of the fungus. Small black resting bodies (sclerotia) of the fungus develop within the white covering of the rotting plant tissue. The fungus survives from season to season in the form of these sclerotia, which serve as the source of inoculum for initial infection. The pathogen is favored by cool, moist weather. Conditions of high humidity with dew formation and temperatures ranging from 60 to 70°F (15 to 21°°C) are optimal for disease development (19).

CELERY MOSAIC (caused by celery mosaic virus, CeMV). Celery mosaic virus, a minor disease in Florida celery, was formerly called western celery mosaic virus. It is confined to plants in the celery family (Umbelliferae), and in addition to celery, mockbishopweed (*Ptilimorium capillaceum*) and wild cherry (*Apium leptophyllum*) are host plants. The disease causes foliage to mottle (producing light and dark green areas together on the leaf) and become distorted and twisted. Plants may also become stunted. Although leafminers have been shown to transmit the virus, aphids are the principal vector,

spreading the disease from volunteer celery or weeds in the family Umbelliferae that serve as hosts. Both celery mosaic virus and cucumber mosaic virus are transmitted by aphids in a stylet-borne, nonpersistant manner, meaning that an aphid can pick up virus particles on its mouthparts (stylet) from an infected plant and transfer them to a healthy plant without the virus circulating through the aphid's body. There is no delay time from when the aphid acquires the virus to when it transmits it, and the aphid is able to transmit the virus for only a short period of time. This type of transmission can occur within seconds, and insecticides are therefore ineffective in preventing virus spread (19).

CUCUMBER MOSAIC (caused by cucumber mosaic virus, CMV). Cucumber mosaic virus is worldwide in distribution and has a wide host range, including plants in ten families in Florida. Celery, cucumber, squash, cantaloupe, tomatoes and pepper have been the principal crops affected. The most important source plant for the virus in Florida is a weed, creeping dayflower (*Commelina* spp.), which is commonly found in ditchbanks, non-crop areas, and moist fields with organic soils, where celery is grown. The virus concentration is low in this host, but the weed's closeness to celery fields and its attractiveness to aphids increase the chances of its spread to celery (19).

Symptoms of cucumber mosaic can range from a mild mosaic to severe deformation and stunting of the plant. The disease also causes stalk pitting. Although mechanical transmission through plant sap can spread the virus within the field, the primary means of transmission is by aphids, in a nonpersistent manner, as discussed above. The most common aphid vectors of celery mosaic and cucumber mosaic virus in Florida are the green peach aphid (*Myzus persicae*) and the cotton aphid (*Aphis gossypii*) (19).

Chemical Control

The most frequently used fungicides on celery in Florida are chlorothalonil (Bravo®/ Terranil®/Echo®/Daconil®), azoxystobin (Amistar®/Quadris®), and propiconazole (Tilt®). Copper compounds, maneb, and streptomycin are used occasionally. Other strobilurins registered for use in celery include trifloxystrobin (Flint®), pyraclostrobin (Cabrio®), and fluoxastrobin (Evito®). Fludioxonil is available alone (Maxim®) or in a mixture with cyprodinil (Switch®). Mefenoxam (Ridomil Gold®), fosetyl (Aliette®), DCNA (Botran®), phosphite, sulfur, potassium bicarbonate, hydrogen peroxide, chloropicrin (Chlor-O-Pic®/Picfume®), metam sodium (Vapam®), and 1,3-dichloropropene (Telone®) are also available for use on celery in Florida.

CHLOROTHALONIL. Chlorothalonil is a broad-spectrum nitrile fungicide used by celery growers for the management of Cercospora (early) blight, Septoria (late) blight, and basal stalk rot. It is the principal fungicide used by Florida celery growers for early blight. The price of chlorothalonil is approximately $9 per pound of active ingredient, and the average cost per application between 2004 and 2007 was $11 per acre (15). Chlorothalonil may be applied up to seven days before harvest (PHI= 7 days), and the REI under the Worker Protection Standard is 12 hours.

Between 2004 and 2007, chlorothalonil has been applied between 3 and 11 times to 100 percent of celery acreage in Florida. During these years, average application rates have ranged from 0.84 to 1.4 pounds of active ingredient per acre, and total statewide annual usage has ranged from 11,000 to 26,000 pounds of active ingredient (15).

AZOXYSTROBIN. Azoxystrobin is a broad-spectrum strobilurin fungicide used by celery growers for the management of Cercospora (early) blight, Septoria (late) blight, and other fungal pathogens. The price of azoxystrobin is approximately $120 per pound of active ingredient, and the average cost per application between 2006 and 2007 was $37 per acre (15). Azoxystrobin may be applied up to the day of harvest (PHI= 0 days), and the REI under the Worker Protection Standard is 4 hours.

Between 2006 and 2007, azoxystrobin has been applied to 50 to 100 percent of the celery acreage in Florida. During these years, average application rates have ranged from 0.19 to 0.25 pounds of active ingredient per acre, and total statewide annual usage has ranged from 600 to 700 pounds of active ingredient (15).

PROPICONAZOLE. Propiconazole is used occasionally in the management of early blight (Cercospora) and late blight (Septoria). It is applied when disease pressure is high. The price of propiconazole is approximately $95 per pound of active ingredient, and the average cost per application between 2006 and 2007 was $11 per acre (15). Propiconazole may be applied up to 14 days before harvest (PHI= 14 days), and the REI under the Worker Protection Standard is 24 hours.

Between 2006 and 2007, propiconazole has been applied to 30 to 60 percent of the celery acreage in Florida. During these years, the application rate has been 0.11 pounds of active ingredient per acre, and total statewide annual usage has ranged from 100 to 200 pounds of active ingredient (15).

Use of Chemicals in IPM Programs

For diseases which are expected yearly, prophylactic measures are required. Disease forecasting systems for early blight are available in the Everglades production area. Growers scout their fields all spring for early and late blight and apply chemical controls only as needed.

Cultural Control

Damage from bacterial blight and brown stem may be reduced somewhat by planting seed at least one-year old, avoiding the application of foliar nitrogen and the over-fertilization of soil-applied nitrogen during conditions favorable to the bacteria, and avoiding worker and farm equipment contact with wet plants. There are also resistant varieties available, but overall the choice of celery varieties is limited (19).

Planting only disease-free transplants can reduce the incidence of early blight. There are also celery varieties that are less susceptible to the disease, such as Early Belle and June Belle. Late blight can be avoided by using three-year old seed (19).

Pink rot is primarily managed by flooding the soil during the summer months, continuously or off and on during six weeks, which reduces the number of viable sclerotia available for infection. Additional cultural controls for pink rot include rotating with a non-susceptible crop such as sweet corn, and burying sclerotia and plant debris by turning the soil 6 to 8 inches (15 to 20 cm) deep (19).

Rhizoctonia stalk rot can be managed by following a series of steps, the majority of which aim to maximize seedling growth and health, thereby reducing the time that young plants are susceptible to the disease. These steps include using only healthy and disease-free seed and transplants, avoiding deep setting of transplants, planting when soil temperature allows for rapid germination, using crop rotation when possible, minimizing plant debris left on the soil surface during land preparation, controlling soil insects and nematodes that can weaken the plant, avoiding over seeding and transplanting too closely, and avoiding moving soil onto the stems during cultivation operations (19).

Isolation of celery fields, maintanence of a celery-free planting period every year, and adequate management of aphid vectors can help to reduce the incidence of celery mosaic. Since the main source of infection is within the celery crop, the most important management tactics are preventing the spread from one season to another and starting with healthy transplants. Cucumber mosaic, on the other hand, is usually spread from the dayflower weed host, and transmission to celery from aphid buildup on ditchbank weeds can be prevented by adequate ditchbank sanitation, particularly during aphid movements in the late fall and late spring (19).

Biological Control

Two microbes are currently registered for use in celery for suppression of pathogenic diseases. *Bacillus subtilis* (Serenade®) and *Bacillus pumilus* (Sonata®) are currently being assessed for their utility in disease control.

Nematode Management

Nematode Pests

Plant-parasitic nematodes are microscopic roundworms, found in soils, which primarily attack plant roots. General symptoms of nematode damage include stunting, premature wilting, leaf yellowing and related symptoms characteristic of nutrient

deficiencies. Stunting and poor stand development tend to occur in patches throughout the field as a result of the irregular distribution of nematodes within the soil. Root-knot nematodes are the main nematode pest of celery on muck soils and are therefore the principal nematode celery pest in Florida. On sandy soils, where there is presently no celery production, the most important nematode pests are sting, root-knot, awl and stubby-root nematodes (22).

Chemical Control

Florida celery growers do not practice chemical nematode management (19,22).

Cultural Control

The principal means of managing nematode populations in Florida celery is by flooding. During the hottest months of the year, fields that are out of production are surrounded by dikes and flooded, which kills nematodes by oxygen starvation. Between four and 12 weeks of flooded conditions are necessary, and alternating periods of flooded and drained conditions work best. Flooding is the exclusive method of nematode management in production fields. Celery planted in the early fall on muck soils that have not been flooded may experience severe damage from nematodes (19,22).

Weed Management

Weed Pests

Weeds compete with the crop plant for moisture, nutrients, light and space and can interfere with harvest operations. Additionally, many weed species serve as alternate hosts for common celery pests such as leafminers, armyworms, loopers, and aphids, as well as plant pathogens and nematodes. Since weeds can also provide shelter and food for natural enemies of celery pests, weed management strategies should adequately address the positive and negative role of weeds in and around the celery field.

Adequate management of weeds in celery is particularly important early in crop growth. Weed competition during the first four weeks after transplanting may cause reductions in harvest quality grades of up to 40 percent (23). The most important weed pests in Florida celery production are yellow and purple nutsedge (*Cyperus esculentus* and *C. rotundus*), amaranth (*Amaranthus* spp.), purslane (*Portulacca oleracea*), and various grasses, particularly large crabgrass (*Digitaria sanguinalis*), goosegrass (*Eleusine indica*), and barnyardgrass (*Echinochloa crusgalli*). Spreading dayflower (*Commelina diffusa*), Florida pellitory (*Parietaria floridana*), lambsquarters (*Chenopodium album*), tall water hemp (*Acnida cannabinus*), yellowcress (*Rorippa* sp.), mock bishopweed (*Ptlimnium capillaceum*), common ragweed (*Ambrosia artemisiifolia*), eclipta (*Eclipta alba*), and cudweed (*Gnaphalium* spp.) can also be severe.

NUTSEDGE (*Cyperus* spp.). Yellow nutsedge (*C. esculentus*) and purple nutsedge (*C. rotundus*) constitute the greatest weed problem in Florida celery. Both of these perennial sedges are found in disturbed habitats throughout Florida and the southeast U.S. Yellow nutsedge may produce some seed but reproduces primarily by rhizomes and tubers. The first plant develops rhizomes, which end in bulbs or tubers that produce new plants. Tuber production is favored by low nitrogen levels and high temperatures (27 to 33°°C, or 80 to 91°F). It is tolerant of high soil moisture but is intolerant of shade. Purple nutsedge is also able to reproduce from tubers when conditions are harsh, making it difficult to control. Unlike the rhizomes of yellow nutsedge, purple nutsedge rhizomes growing off the first plant produce new plants in a series ("tuber-chains"). The plant also reproduces by seed to a limited degree. Although purple nutsedge is also intolerant of shade, it is able to survive a wide range of environmental conditions, growing well in nearly all soil types and over a range of soil moisture, soil pH, and elevation. It is also able to survive extremely high temperatures (24,25).

AMARANTH (*Amaranthus* spp.). Amaranths (pigweeds) are broadleaf summer annuals with erect stems that can grow to 2 meters (6.5 feet) tall. Several species of amaranth may be present in Florida, but the most problematic in celery are spiny amaranth (*A. spinosus*), smooth pigweed (*A. hybridus*), and livid amaranth (*A. lividus*). Amaranths or pigweeds reproduce solely by seed, producing very small, dark seeds. Smooth pigweeds

flower from July to November and spiny amaranth flowers from June to October. They prefer open areas with bright sunlight (24,25).

PURSLANE (*Portulaca oleracea*). Purslane is a broadleaf summer annual with a taproot and multiple branched stems that often form large mats. It reproduces by seed, flowering from August to October. Being resistant to drought, it is difficult to kill (24,25).

BARNYARD GRASS (*Echinochloa crusgalli*). Barnyard grass is a summer annual grass that can reach 2 to 4.5 feet (0.6 to 1.4 m) tall. The plant has shallow, fibrous roots, and roots at the lower nodes, sometimes forming large clumps. Barnyard grass reproduces only by seed (24,25).

Chemical Control

The most commonly used herbicides on celery in Florida are prometryn (Caparol®), and sethoxydim (Poast®). Metolachlor (Dual®) and glyphosate (Roundup®) are used occasionally. Bensulide (Prefar®), carfentrazone (Aim®), clethodim (Select®), pyraflufen (ET®), oxyfluorfen (Goal®), linuron (Lorox®), pelargonic acid (Scythe®), and trifluralin (Trilin®) are also available for use on celery in Florida, although trifluralin is only used on sandy soils (23).

PROMETRYN. Florida celery growers most commonly use the selective triazine herbicide prometryn in the management of annual grasses and broadleaf weeds when they are in the seedling stage. The price of prometryn is approximately $9 per pound of active ingredient, and the average cost per application between 2004 and 2007 was $2 per acre (15). The REI under the Worker Protection Standard is 12 hours.

Between 2004 and 2007, prometryn has been applied between once (full application) and 3 times (split application) to 100 percent of celery acreage in Florida. During these years, average application rates have ranged from 0.20 to 0.25 pounds of active ingredient per acre, and total statewide annual usage has ranged from 700 to 2,400 pounds of active ingredient (15).

SETHOXYDIM. Sethoxydim is a selective post-emergence herbicide used in the management of annual and perennial grass weeds. The price of sethoxydim is approximately $100 per pound of active ingredient, and the average cost per application between 2004 and 2007 was $23 per acre (15). The REI under the Worker Protection Standard is 12 hours and the PHI is 30 days.

Between 2004 and 2007, sethoxydim has been applied to 30 to 100 percent of the celery acreage in Florida. During these years, average application rates have ranged from 0.13 to 0.28 pounds of active ingredient per acre, and total statewide annual usage has ranged from 250 to 600 pounds of active ingredient (15).

METOLACHLOR. Metolachlor is a chloroacetamide herbicide used for the management of annual and perennial broadleaf and grassy weeds. It is available under a special local needs registration. It is applied when the celery is transplanted. The price of metolachlor is approximately $14 per pound of active ingredient, and the average cost per application between 2005 and 2006 was $25 per acre (15). The REI under the Worker Protection Standard is 24 hours and the PHI is 62 days.

Between 2005 and 2006, metolachlor has been applied to approximately 50 percent of the celery acreage in Florida. During these years, average application rates have ranged from 1.7 to 1.8 pounds of active ingredient per acre, and total statewide annual usage has ranged from 2,800 to 3,000 pounds of active ingredient (15).

GLYPHOSATE. Glyphosate is a broad-spectrum systemic herbicide used occasionally in the management of annual and perennial grasses, sedges and broad-leaved weeds. Applications are made pre-plant, and no residual weed control is provided. The price of glyphosate is approximately $10 per pound of active ingredient, and the average cost per application in 2004 was $20 per acre (15). The REI under the Worker Protection Standard is 12 hours and the PHI is 57 days.

In 2004, glyphosate was applied to 15 percent of the celery acreage in Florida. The application rate was 2.1 pounds of active ingredient per acre, and total

statewide annual usage was 1,000 pounds of active ingredient (15).

Cultural Control

Weeds in celery can be effectively managed with cultivation. However, celery roots can be easily damaged by close cultivation, and the quality of the celery harvested may therefore be decreased if the roots are pruned during either mechanical cultivation or hand hoeing (23).

Key Contacts

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