Strawberry Crimp Disease - *Aphelenchoides besseyi*
Strawberry Crimp Nematode - *Aphelenchoides fragariae*
Leaf Nematode / Foliar eelworm - *Aphelenchoides ritzemabosi*

Strawberry Crimp Nematode - *Aphelenchoides fragariae*

Risk of Introduction: A. fragariae is currently targeted in regulatory programs worldwide (O'Bannon and Esser, 1987). It is one of a group of nematodes that are presently targeted in regulatory programs in Taiwan (Tsay, 1995). In Russia, the principal nematodes designated for quarantine measures are A. fragariae, A. ritzemabosi, Heterodera [Globodera] rostochiensis and Ditylenchus angustus (Anon., 1978). Plant certification schemes of clean strawberry stocks can successfully control the introduction and spread of A. fragariae and A. ritzemabosi (Tacconi and Lamberti, 1994). Quarantine checks intercepted A. fragariae on strawberry seedlings imported to Tianjin, China from the USA (Zhang and Wang, 1989).

Hosts/Species Affected : Over 250 plants in 47 families are recorded as hosts of A. fragariae (Sturhan, 1962). Some earlier records may refer to A. ritzemabosi on 28 hosts including strawberry, aster, begonia, etc. (Siddiqi, 1975). Hosts mostly include ferns and members of Liliaceae, Primulaceae and Ranunculaceae compared with A. ritzemabosi which mainly parasitizes members of Compositae. It has been recorded on 27 plant species in California, USA (Siddiqui et al., 1973 A. fragariae attacks above-ground parts of plants and may be endo- or ectoparasitic. In begonias, the nematode feeds on, and destroys, mesophyll cells of the leaves and may cause reddening along the veins causing the entire leaf blade to appear red; severe necrosis may result in the presence of Xanthomonas begoniae (Riedel and Larsen, 1974). Red plant symptoms are seen on strawberry var. Royal sovereign, Laxton's King George, Duke and Aberdeen Standard (Goodey, 1933).

Biology and Ecology: Aphelenchoides fragariae is an obligate parasite of above-ground plant parts and may be ecto- or endoparasitic. On strawberry it is ectoparasitic on folded crown and runner buds, feeding causing small, dry brown areas delimited by the midrib and major veins. The nematodes may be found feeding endoparasitically on leaf tissues and have occasionally been found in fruit pulp (Tacconi, 1972). In violets, it is also ectoparasitic in the unopened leaf and flower buds and has been found within the ovary. It is endoparasitic in leaves of ferns, begonias, peonies, etc., the feeding causing leaf-blotch symptoms. The nematode enters the leaf through the stomata when the surface is covered with a thin film of water (Klingler, 1970), or by penetrating the epidermis of the under surface (Strümpel, 1967). Both A. fragariae and A. ritzemabosi showed peak populations in March to May and November to January and were influenced by moisture and temperature (Szczygiel and Hasior, 1972).

Symptoms: On strawberry, A. fragariae causes malformations of the shoot such as twisting and puckering of leaves, discoloured areas with a hard and rough surface, undersized leaves with crinkled edges, reddening of petioles, short internodes of runners, reduced flower trusses with only one or two flowers and death of the crown bud (Dicker, 1948; Franklin, 1950; Iyatomi and Nishizawa, 1951; Ogilvie and Thompson, 1936). Ectoparasitic feeding on folded crown and runner buds causes small dry, brown feeding areas which can be seen on expanded leaves usually near the mid-rib; occasionally the nematodes are found in strawberry fruit pulp (Tacconi, 1972). Endoparasitic feeding within leaf tissue produces typical leaf-blotch symptoms. The strawberry disease referred to as Spring dwarf, Spring crimp and Red plant, may be due wholly or partly to A. fragariae; sometimes these symptoms could be due to other nematodes (A. ritzemabosi, Ditylenchus dipsaci) or caused by bacteria or frost. On flowering plant leaves, the feeding areas appear as irregular, water-soaked patches later turning brown, violet or purple.

Stokes (1979) describes leaf lesions and bud abnormalities on ornamental plants caused by A. fragariae in Florida, USA. The nematode causes die-back disease of lilies, in which leaves, flower buds and fruits turn brown and die.

Reproduction and life cycle: A. fragariae is bisexual and amphimictic with n=2 (A. ritzemabosi and A. besseyi are also amphimictic with n=4 and n=3, respectively) (Cayrol and Dalmasso, 1975). In the leaves of Lorraine begonia the life cycle is completed in 10-11 days at 18°C. The eggs hatch in 4 days and the juveniles mature in 6-7 days; about 32 eggs are laid by a single female (Strümpel, 1967).

Survival: The nematode cannot survive in soil without a host for more than 3 months (Szczygiel and Hasior, 1971). It survived in a dormant state in fern fronds buried in soil for at least 46 days (Stewart, 1921).

No change in nematode population per number of hearts occurred when strawberry plants infested with A. fragariae and A. ritzemabosi were stored at temperatures of 14-15°C or in an unheated glasshouse in winter. However, at 20°C, the population increased several times. Under cold-storage conditions at -2 to -1°C it performed well in plant tissues (Tacconi, 1972). Relatively few individuals of A. fragariae survived at -20°C (Hirling, 1972). Under dry conditions, A. fragariae survived in damaged lily leaves for more than 600 days (Yamada and Takakura, 1987).

Aphelenchoides besseyi- Strawberry Crimp Disease

Aphelenchoides besseyi is a plant pathogenic nematode. It is sometimes referred to as rice white tip, spring dwarf, strawberry bud, or strawberry crimp disease nematode. This foliar nematode is found in Africa, North, Central, and South America, Asia, Eastern Europe, and Pacific Islands.

Life Cycle: The nematodes survival stage is to remain anhydrobiotic in seed until planting. As surrounding plants grow the nematodes become active and feed on meristematic tissue. A. besseyi reproduces amphimicticly although parthenogenesis can take place. As the plant begins to reach reproductive maturity the number of nematodes increases dramatically. The nematodes migrate to feed on reproductive structures eventually settling in the developing rice seed. As the kernel dries the nematode slowly desiccates and can remain viable in the kernel for up to three years. The life cycle of A.besseyi is generally short consisting of around 8–12 days.[4][6] This species is thermophilic. The lower threshold for development is 13°C and the optimum temperature varies between 23°C and 30°C. The sum of effective temperatures for the development of one generation is 80 degree-days.[7]

Host Parasite Relationship: A. besseyi is an ectoparasitic nematode which means it feeds on the plant tissue externally. This nematode is most often associated with a disease in which the leaves of the rice plant turn white in the meristematic regions followed by necrosis.[4][8] These nematodes can also cause stunting and sterility with yield losses of up to 50% reported[4][9]

Management: The most common management practice for A. besseyi is to maintain clean seed stocks. Since the nematode survives in the seed it is fairly easy to control. Seed can be chemically treated to kill nematodes or can be cleaned using a method in which the seed is initially soaked in cool water to activate the nematode and then briefly soaked in hot water to kill them. These seeds can then either be directly planted or quickly dried for storage.

Aphelenchoides ritzemabosi- Leaf Nematode / Foliar eelworm

Aphelenchoides ritzemabosi (Black currant nematode, Chrysanthemum foliar nematode, Chrysanthemum leaf nematode, Chrysanthemum nematode, Chrysanthemum Foliar eelworm) is a plant pathogenic nematode. It was first scientifically described in 1890 in England.

Hosts and Symptoms: This nematode has a wide host range. Among the most important species affected are Chrysanthemums and strawberries. A. ritzemabosi is a migratory foliar feeding nematode. It can feed both ectoparasitically and endoparasitically, with the later causing the most significant damage. When adequate moisture is present, this nematode enters the leaves and feeds from inside the tissue. Typical damage is characterized by necrotic zones between the veins of the leaves. Its lifecycle is short; only ten days from egg to mature adult. A single female can lay as many as 3,500 eggs. This pest can be difficult to control. Host plant resistance, hot water treatments, and predatory mites are recommended.

Disease cycle: A. ritzemabosi is an endoparasitic nematode, meaning that it feeds on plant tissue from the inside of the cell.[6] Adult nematodes infest the leaves of their host plant by swimming up the outside of the stem in a film of water. This can only happen when the relative humidity is very high.[7] Once it has reached a leaf it enters through the stomata to begin feeding in an endoparasitic fashion.[3] Once inside the host it is capable of invading and infecting host tissue at all life stages, other than the egg. The more mature stages show an improved ability to migrate through host tissue.[3] When the growing season of the host comes to an end the nematode goes into a quiescent state overwintering inside the leaf tissue. When spring comes they end their quiescent state then find and infest a new host.[8]

A. ritzeambosi is also capable of feeding ectoparasitically, from the outside of the cell. It has been known to feed ectoparasitically on the buds of some plants such as strawberry and black currants. Above ground ectoparasitic feeding can only happen in events of prolonged high humidity or other circumstances providing a long term film of water on the plant which protects the nematode from exposure. Ectoparasitic feeding also happens on the roots in the soil.[6] All of this happens in an extremely short amount of time, it takes around 10 days for A. ritzembosi to go from egg to adult. All life stages are vermiform and migratory. [5]

Reproduction: Studies have shown that in optimal conditions a single female A. ritzemabosi can produce up to thousands of offspring in the period of about a month.[9] French & Barraclough (1961) obtained a maximum number of 3,500 progeny from a single A. ritzemabosi female after 38 days at mean greenhouse temperatures of 17° to 23 °C. Temperature influence on reproduction showed that higher temperatures generally lead to more reproductive actions. No reproduction was observed at temperatures of 8 degrees Celsius.[9] Fertilized females go on reproducing for six months without further fertilization [10] In chrysanthemum leaves, the female lays about 25-30 eggs in a compact group. These eggs hatch in 3–4 days and the juveniles take 9–10 days to reach maturity. The total life cycle takes 10–13 days [11] In susceptible varieties of Chrysanthemum, the female remains in one place within the leaf as it feeds on adjacent cells and continuously lays eggs. In resistant varieties, the female moves through the leaf laying only a few eggs as it goes. Few, if any of the juveniles make it to maturity.[11] Like many other plant parasitic nematodes, A. ritzemabosi has the ability to reproduce on fungal tissue, suggesting that soil fungus may contribute to the nematode's survival when no host is available.[12] Laboratory tests have shown that Botrytis cinerea and many Rhizoctonia species of fungi are more conducive to A. ritzeambosi growth and reproduction. These fungi are used to culture and propagate other Aphelenchid species as well.[13] In adult females, the eggs can be seen developing inside their bodies before they are deposited to hatch. If an adult female is cut off from a reliable supply of food it has been observed that the egg will disappear from view, evidently being aborted and reabsorbed by the female.[9]

Environment: A.ritzeambosi has a very wide range. In the US, its distribution is restricted to California, Colorado, Florida, and Wyoming. It is widespread in Mexico. It is also present but restricted in Asia, including many provinces of China, Japan, Iran, and India. It is also present throughout Europe from Portugal to Siberia; it was once present in Denmark but has been eradicated. It is widespread in South Africa, and the Canary Islands.[14] A. ritzemabosi is more commonly associated with temperate climates, even though it can be found in both tropical and temperate localities. It is best suited to thrive and reproduce when in highly humid environments, where it tends to be more active in infesting hosts than in dryer environments.[15] the optimal temperature for reproduction is 17 °C-23 °C.[16]

Management: Infected leaves and plants should be removed and destroyed. Since this nematode relies on moisture to move up the plant and between plants, care should be taken to avoid periods of wetness. Drip irrigation is preferable over overhead spray irrigation for this reason. This nematode is susceptible to elevated temperatures. A hot water treatment at a temperature of 115 degrees Fahrenheit for five minutes of dormant plant materials such as bulbs, runners or cuttings intended for propagation can be used and is effective at eliminating most nematodes that may be infesting the plant material.[17] Sanitation of equipment is also important to controlling the nematode. Pots potting soil, and tools should be cleaned by baking or steaming at 180-200 degrees Fahrenheit for 30 minutes [18]. Care must be taken so that the temperatures needed to eliminate the infesting nematodes does not irrevocably harm the plant material.[3] Parathion has proven to be a potent chemical control of A. ritzemabosi, especially in chrysanthemum.[3] Host-plant resistance is also used to control A. ritzemabosi. The following cultivars of Chrysanthemum are resistant to this pest: Amy Shoesmith, Delightful, Orange Beauty, and Orange Peach Blossom. These are listed as resistant but not immune. This implies that the plant may still be attacked by adult nematodes but reproduction is highly reduced if not prevented.[20]

Importance: Infection of various plants by A. ritzemabosi is likely to cause some degree of yield loss to growers where the nematode is present since photosynthetic area of the leaves is damaged or destroyed as the nematodes feed and reproduce.[21] However, this nematode is not considered to cause economic loss unless environmental conditions are very suitable. A. ritzemabosi is a serious pest of strawberry in Ireland, where yield reductions up to 60% have been recorded. The crown weight of strawberry cv. Senga Sengana was reduced by 51% by A. ritzemabosi. This damage results in fruit yield loss of up to 65%. A. ritzemabosi infections can reduce the number of runners by up to 25-30%. The level of susceptibility varies among cultivars. An infection by A. ritzemabosi can cause average yield losses of an estimated 53.4% in the strawberry variety Korallovaya 100. The variety Yasna seems to be somewhat less susceptible to A. ritzemabosi than Korallovaya 100 or Muto. This organism is a 'C' rated pest in the U.S. state of California, meaning that it is not subject to state enforcement outside of nurseries except to retard spread or to provide for pest cleanliness in nurseries. For a sense of how that relates to other plant pests, an 'A' rated pest is an organism of known economic importance subject to action enforced by the state (or County Agricultural Commissioner acting as a state agent) involving: eradication, quarantine regulation, containment, rejection, or other holding action such as Aphelenchoides besseyi (strawberry summer dwarf nematode).[25]

Northern Root-knot Nematode – *Meloidogyne hapla*

Distribution:

M. hapla is extremely widely distributed, particularly in temperate regions and the cooler, higher altitude areas of the tropics. According to Whitehead (1969), M. hapla only flourishes at high altitudes above 6000 feet in East Africa (Kenya, Tanzania and Uganda), despite the abundance of host plants at lower altitudes. In Queensland, Australia, M. hapla was not found as far north as M. javanica (Colbran, 1958). Taylor and Buhrer (1958) reported that in the USA, M. hapla was the commonest root-knot nematode north of 39°N.

The infective second stage juveniles are found in the soil where they hatch from the eggs. The second stage penetrates a suitable root and all subsequent stages are located within the root tissue of the host where they remain as sedentary endoparasites with the exception of the adult vermiform male which may escape from the root into the soil.

M. hapla is extremely polyphagous, attacking a wide variety of crops and weeds. Goodey et al. (1965) listed over 550 hosts and many more have been added since then. The species has recorded hosts in most of the higher plant families and attacks both herbaceous and woody plants. However, many grasses and cereals appear to be non-hosts. Carter (1985) provided a review of the recorded hosts.

Typical symptoms of attack include a galling of the root system, the galls being relatively small and subspherical, often with a marked proliferation of small roots at the site of the gall (this is in contrast to the symptoms caused by other common species of Meloidogyne). In potato tubers, brown spots appearing in the tubers after the females commence egg production may identify infection sites. Severe attack by M. hapla results in impaired root function and concomitant stunting of the above ground parts leading to a reduction in yield. Roots typically possess galls along the length, with an overall reduction in root system size.

Biology / ecology

M. hapla is an obligate sedentary endoparasite of plant roots and tubers. The second stage infective juvenile penetrates the root and settles down within the cortex. As with all root-knot nematodes, a giant cell system of trophic cells is formed by the plant in response to secretions from the nematode. With each moult the nematode becomes more obese, although males become vermiform at the last moult and then emerge into the soil. The obese female swells enormously and produces numerous eggs (typically about 500) in a protective gelatinous matrix.

Unlike many root knot nematodes, M. hapla can withstand cold, eggs and juveniles surviving field temperatures below 0°C. However, it seems to be less tolerant of high temperatures than Meloidogyne incognita, for example. The optimum temperature for invasion and growth of M. hapla is in the range 20-25°C, a mean temperature of 27°C being inimical to development.

M. hapla is broadly similar to other members of the genus and normally requires the service of an experienced nematologist to identify to species level with any certainty. A suite of morphological characters, including the form of the perineal pattern of the mature female and the length and form of the second stage juvenile tail facilitate identification. Confusion with Meloidogyne chitwoodi is possible and PCR assays have been developed to assist in the rapid differentiation of the species. The galls formed by this species are usually rather atypical of root-knot nematodes in general in that they are often rather discrete and globular and arranged along the root. This symptom may be confused with galling by Nacobbus aberrans, the false root-knot nematode, and care should be taken to examine the nematodes inside the gall to confirm their identity.

The nematode may be associated with other pathogens, including bacteria (such as Pseudomonas caryophylli) and fungi (such as Fusarium oxysporum, Rhizoctonia solani and Verticillium dahliae).

Impact

M. hapla attacks nearly all temperate vegetables of economic importance and is well known as being capable of causing considerable reductions in yield, even to the point of total crop loss. In the field, crops including lucerne, groundnut, potato, carrot, sugarbeet, strawberry, pyrethrum and onion may be severely affected. For further quantitative information, see Luc et al. (1990) and Evans et al. (1993).

Detection / Inspection

M. hapla may be detected within the galled roots and tubers of the host by careful dissection and examination under the stereomicroscope. The infective juveniles may be recovered from soil using standard extraction methodologies as may the adult vermiform males when these occur.

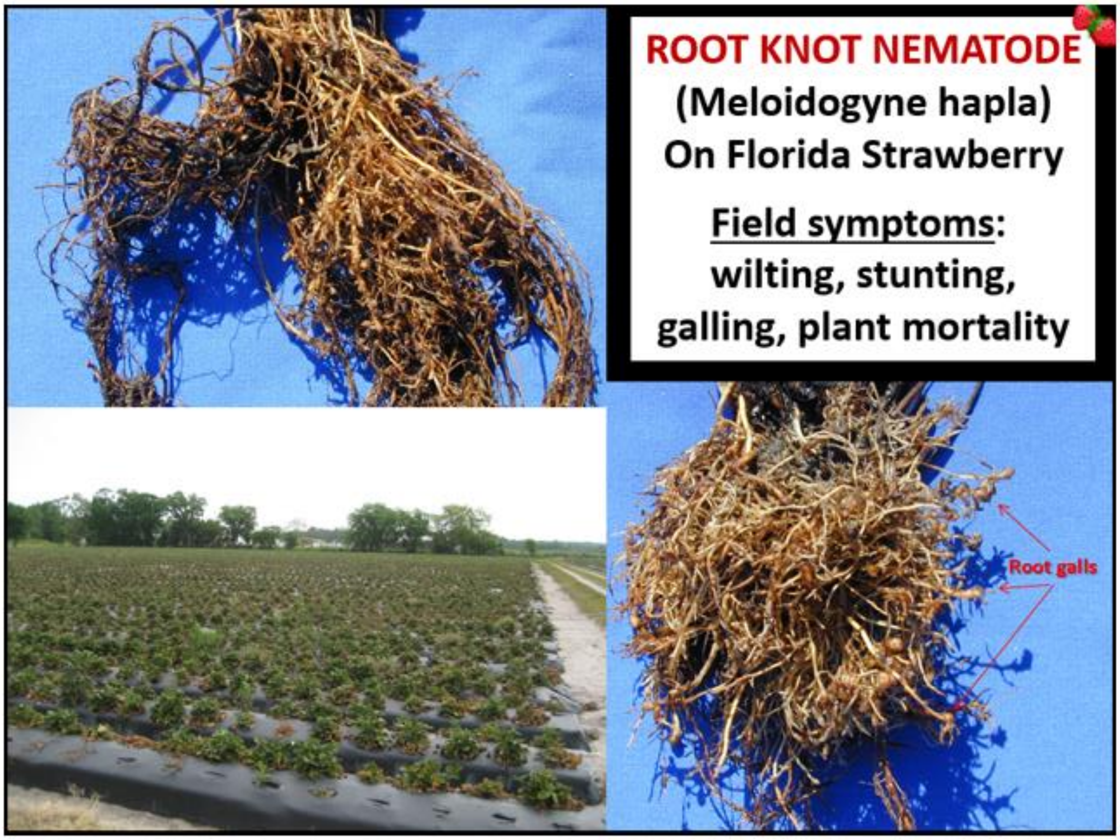
Prevention / Control

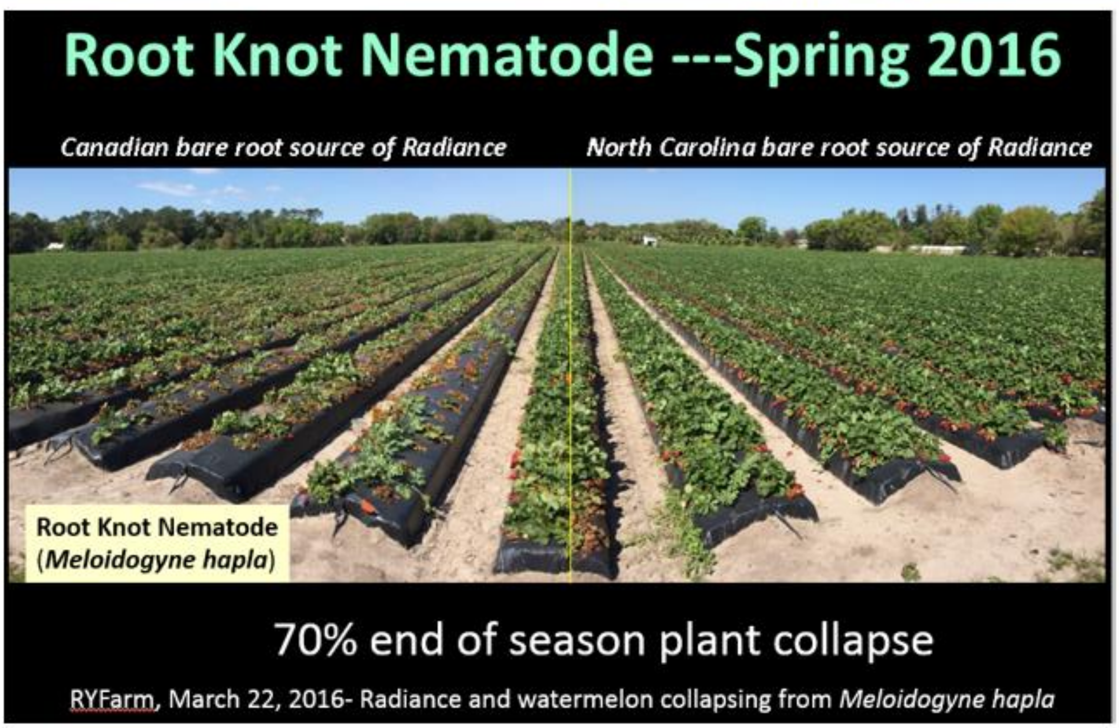
Various methods have been used to cleanse planting material, including hot water treatment (McDonald and Misari, 1976; Zunke, 1981) and a range of nematicidal drenches. Treatment in the field also relies upon the application of nematicides although frequent rotation with cereals or other graminaceous non-host crops may also be efficacious. Typically, two years out of strawberries in the rotation sequence is recommended in Michigan (see Warner, 2015). Many crops have potential for development of resistant or tolerant varieties. Cultivars with polygenic resistance to M. hapla have been bred in Europe and varieties differ in their tolerances to the nematode. However, this information is not always reported or readily available

For general information on the use of fumigant nematicides see Noling. (2016) and Evans et al. (1993). Both granular and liquid formulations have been used to control this nematode. More recent papers on this subject include LaMondia (1994), Johnston et al. (1995, 1996), Phipps et al. (1995) and Phipps and Eisenback (1996).

Table 17. Hosts of Nematodes That Attack Strawberries.

Plant category	Foliar nematode, *Aphelencoides fragariae*	Root knot nematode, *Meloidogyne hapla*
Cultivated plants	Asplenium	Alfalfa
	Begonia	Beans
	Dahlia	Carrot
	Ferns	Cole crops
	Figs	Eggplant
	Gloxinia	Grapes
	Hibiscus	Lettuce
	Lilies	Melons
	Narcissus	Peas
	Primrose	Peppers
	Viburnum	Potato
	Violets	Sugar beet
		Tomato
Weeds and native plants	Fanworts	Field bindweed
	Ferns	Lambsquarters
	Common groundsel	Mallow
	Limnophila	Mustards
	Nightshades	Nightshades
	Oxalis	Sowthistle
	Pondweeds	
	Shepherd's-purse	
	Speedwell	


ROOT KNOT NEMATODE
(Meloidogyne hapla)
On Florida Strawberry
Field symptoms:
wilting, stunting,
galling, plant mortality
Root galls


Root Knot Nematode ---Spring 2016
Canadian bare root source of Radiance
North Carolina bare root source of Radiance
Root Knot Nematode
(Meloidogyne hapla)
70% end of season plant collapse
RYFarm, March 22, 2016- Radiance and watermelon collapsing from Meloidogyne hapla


Spring & Summer Dwarf Disease - Aphelenchoides spp.
Flattened, Stunting, aborted flowers and fruit, compact crowns hardened stressed appearance, patchy distribution, distorted tissues within the inner crown. It is a foliar nematode surviving in surface water films.


phelenchoides besseyi
Time T1 ~ 8 weeks post transplant
Time T1 + 2 weeks