College of Agriculture, Food and Environment
Cooperative Extension Service

Plant Pathology Fact Sheet

PPFS-VG-28
CCD-FS-22

Root-knot Nematode
in Vegetable Cropping Systems

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Importance

Root-knot nematodes (*Meloidogyne* spp.) are plant-parasitic roundworms that result in decreased plant vigor and yield, followed by eventual plant death. These microscopic organisms reside in soil and infect plant roots. Root-knot nematodes are the most detrimental plant-parasitic nematode to vegetable crops. If unmanaged, populations of root knot nematode (RKN) increase each year. Severe infestations may result in death of crops and significant economic loss for growers.

Host Range

Root-knot nematodes have wide host ranges that include over 500 plant species. They are known to infect many species of ornamentals, fruits, and vegetables. Most vegetables, including tomato and potato, are susceptible to RKN. A large number of weed species are also susceptible.

Symptoms

Aboveground

Aboveground symptoms result from damage to the root system. Infection of roots by RKN limits the ability of plants to take up water and nutrients from soil. As a result, plants exhibit stunting, wilting, and dieback. More severe aboveground symptoms likely indicate a heavily infected root system. Plants may appear stunted with leaves becoming chlorotic (yellow) and eventually necrotic (brown) (Figure 1). Wilting may occur during periods with high temperatures or dry conditions. Infected plants may also have delayed maturity and lower yields compared to healthy plants.

Figure 1: Plants infected by root-knot nematode may appear stunted with chlorotic leaves, which eventually become necrotic.
Figure 2: Roots infected with RKN develop galls or swollen areas.

Symptomatic plants may first be localized, later expanding to a larger area. It is also common for there to be multiple "hot spots" with high RKN populations within the same field, high tunnel, or garden. Over time, entire plantings can become infected.

Figure 3. The skin of tubers infected with RKN may have a bumpy appearance.

Root Symptoms

Roots infected by RKN develop swollen areas or "knots", known as galls (Figure 2). Severely infected roots may have numerous galls, which fuse together and give roots a distorted appearance. Galls vary in size and shape depending on RKN species, population density, and host crop. It is important to note that different crops develop different symptoms when infected with RKN. Crops such as carrots may develop lateral roots, giving them a hairy look. Sweet potatoes and potato tubers may appear to have bumpy, swollen areas on the surface (Figure 3).

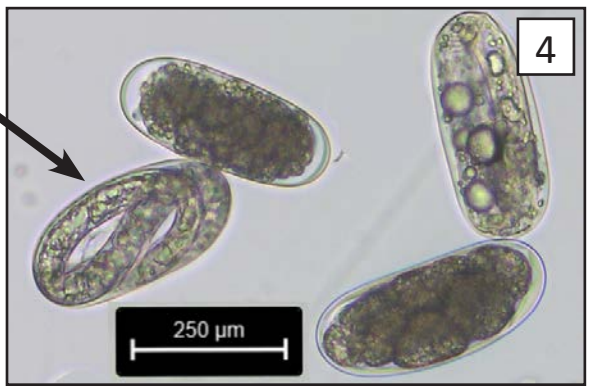
Cause, Nematode Life Cycle & Infection

The most common RKN species in Kentucky are northern root-knot nematode (*Meloidogyne hapla*) and southern root-knot nematode (*Meloidogyne incognita*).

Females can produce up to 1,000 eggs. Eggs may stay inside roots or may end up in soil (Figure 4). Under favorable conditions, eggs can survive in soil for up to a year. All nematodes (plant-parasitic or otherwise) have four juvenile stages (J1 through J4). J1 remain inside the egg (Figure 4). J2 hatch from eggs and travel to infect plant roots (Figure 5); this is the only infective stage. Once they have entered a root as juveniles, most RKN females remain in the root throughout their lives, where they feed and reproduce; they are sedentary endoparasites. Nematodes progress through J3 and J4 stages to adulthood. Occasionally, juvenile RKN become males instead of females and exit the root, where they are non-feeding, mate, and die. Females are globular-shape (Figure 6) while males are vermiform (worm-like) (Figure 7). Enzymes secreted during feeding of RKN induce swelling of plant cells into what are called giant cells. Root galling is an outcome of RKN parasitism and can be observed on plant roots.

Root-knot nematodes are capable of completing multiple life cycles in a single growing season. The number of life cycles and the rate at which the population increases depends on numerous factors, such as soil temperature, soil type, and host susceptibility. Soil temperatures between 65°F and 80°F favor faster life cycle completion. Sandy soil is more conducive, whereas heavy clay may discourage reproduction. Root-knot nematode can complete one life cycle in as little as 25 days under optimal conditions (sandy soil at 81°F).

While RKN can move short distances (typically a few inches) through soil to infect new plants, larger scale movement occurs through movement of infested soil by humans. Transplants, as well as boots, tools, and equipment carrying infested soil are capable of moving nematodes longer distances.



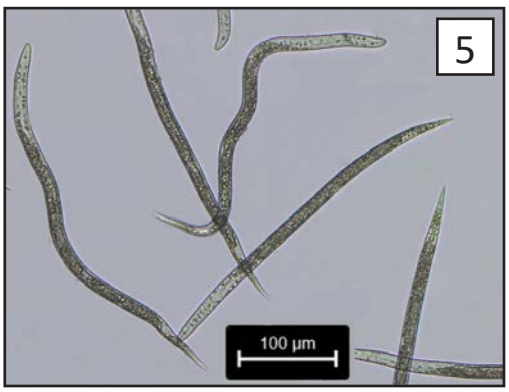


Figure 4: Root knot nematode eggs. The first-stage juvenile (J1) stage is indicated by the black arrow.
Figure 5: Second-stage juvenile (J2) nematodes are motile and begin infection of plant roots.

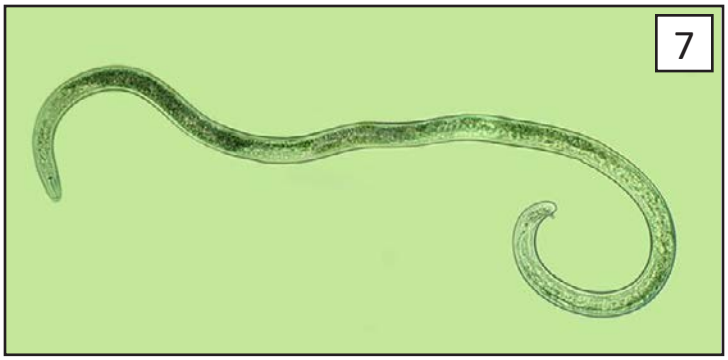


Figure 6: Adult female RKN have a globular form and protrude from roots.
Figure 7: Adult male RKN have a worm-like appearance.

Nematode Testing

Assessing the severity of a field infestation is determined by extracting RKN from soil and plant roots. Many commercial labs offer this service. The number of RKN extracted from soil and roots will determine the level of risk or infection for a particular site or planting. For root infections, more than 1 RKN per gram of root is considered high risk and would require a management strategy. For soil, more than 20 RKN per 100 cc of soil is considered high. Contact a county Extension agent for more information on RKN identification and diagnosis.

Management

Commercial Options (Field & High Tunnel)

Crop Rotation & Plant Selection

Rotating with a non-host or resistant crop is the most effective method for reducing RKN populations. Although RKN has a wide host range, there are resistant or non-host vegetable cultivars (Table 1) that can be used in crop rotations alone or in combination. In order to break the cycle of RKN, host plants (crops, cover crops, and weeds) must be eliminated for at least 2 to 3 consecutive years to provide reliable control of RKN.

Non-host crop species that RKN do not infect or feed on lead to reduced reproduction and an eventual reduction in the overall RKN population. Asparagus, sweet corn, onions, and garlic are non-hosts for RKN, with some exceptions. Many grains, including sorghum, are also non-hosts. Cover crops such as sunn hemp, partridge pea, and cereal rye are non-hosts for RKN, as well as various cultivars of cowpea. These non-hosts, alone or in combination, can be used in a rotation to help break the RKN life cycle.

Some non-hosts are also nematode-suppressive. Nematode-suppressive crops include certain types of marigolds, chrysanthemums, castor bean, partridge pea, velvet bean, vetch, rapeseed (canola), white or yellow mustard, and sesame.

The resistance and host status of some crops can vary among cultivars. Refer to cultivar descriptions when selecting vegetables for crop rotation. Some RKN-resistant cultivars of snap bean, lima bean, sweet potato, English pea, southern pea, broccoli, and tomato are commercially available and can be incorporated into a rotational system. It is important to know which species of RKN is present, as genetic resistance is typically targeted only toward the southern root-knot nematode (*M. incognita*) and may have no impact on the northern root-knot nematode (*M. hapla*). Resistance may be broken if soil temperatures are high.

Resistant rootstocks are another option for introducing resistance into crop rotations. There are many cultivars of tomato rootstock that are resistant to RKN. Tomato cultivars grafted onto resistant rootstocks are available from some transplant producers and can be a viable option for sites with heavy RKN infestations. In trials performed in Kentucky high tunnels, certain rootstocks performed well and were not affected by RKN. Rootstock resistance to RKN may also be broken if soil temperatures are high.

Understanding Host Susceptibility & Resistance Terms

Susceptible crops allow for high levels of nematode infection and reproduction; this makes them a host. The development and yield of susceptible crops will suffer when infected by RKN.

Non-host crop indicates that plant-parasitic nematodes are unable to infect the crop and therefore are unable to reproduce in the presence of that crop. With little to no reproduction occurring, the population of RKN will decrease significantly over time

Suppressive non-host crops reduce nematode populations in soil by depriving them of food and by releasing chemicals that inhibit RKN reproduction and development. Rotating with these plants can provide an effective, non-chemical strategy for managing RKN.

Resistant crops are not absolute non-hosts. They may be infected by plant-parasitic nematodes at reduced levels, and reproduction of those nematodes is reduced. There is a spectrum of resistance—complete resistance (which may also be considered a non-host) to moderately resistant (which may also be considered tolerant). Moderately resistant crops do not completely break the RKN life cycle because they allow nematodes to reproduce, although at significantly reduced levels. Even when moderately resistant/tolerant plants are infected with RKN, they can grow, develop, and produce commercial-level yields.

Weed Management

Many weed species serve as hosts for RKN. It is important to keep plantings free of weeds or volunteer plants, as they may be hosts for RKN and thereby nullify the effect of rotation. Weeds such as amaranth/pigweed, dandelion, and morning glory are hosts for RKN.

Early Planting

RKN reproduction is in part determined by soil temperatures. When soil temperatures are cool (lower than 65°F), RKN reproduction rates are slow to zero. Some susceptible vegetable crops such as radish, lettuce, and spinach can be successfully grown in infested sites because they are grown under cool conditions when RKN is inactive and harvested before soil temperatures increase and RKN can cause significant damage.

Sanitation

Dirty equipment carrying RKN-infested soil is a common way to spread RKN and to introduce RKN into a new field or on-farm location. All tools and equipment should be thoroughly and regularly washed to remove soil particles. Sanitize all pots, benches, and tools before reuse.

If a grower is aware of RKN infestation in one field, they should work in their non-infested or "clean" fields first and then the infested or "dirty" field last. After working in infested fields, tools and equipment should be washed and disinfected. If borrowing equipment, clean completely before using.

Infected transplants and tubers can also introduce RKN into fields and high tunnels. Inspect transplants carefully before planting into fields and high tunnels. If purchasing plant material, be sure to purchase from a reputable source. Infected stock should never be used for propagation.

Chemicals

Fumigation of soil can be used as a management tool in commercial field plantings. However, fumigation is uncommon as a result of cost, regulations, and limited number of commercial applicators who provide the service to small growers. These fumigants, when properly applied, significantly reduce the nematode population, but studies have shown that the effect is temporary. Nematode populations will return to damaging levels within a season in sites replanted to a susceptible crop. Soil fumigants are dangerous to people and animals and should be used with extreme caution. Fumigation is not permitted for use in high tunnels in Kentucky.

Non-fumigant nematicides are labeled for commercial use and can be applied pre- and post-planting for suppression of RKN. These products do not provide absolute control of RKN and should be combined with other cultural control methods. All non-fumigant nematicides, like the fumigants, are dangerous chemicals and should be used with caution. Refer to the "Non-Fumigant Nematicides" table in the *Vegetable Production Guide for Commercial Growers* (ID-36) for a list of registered products.

Biological Control

Products based on microbes or plant extracts are marketed for use in suppressing RKN and other nematodes. Refer to "Biopesticides for Vegetable Disease Management" table in the *Vegetable Production Guide for Commercial Growers* (ID-36) for the most recent list of labeled biocontrol products. In general, biological nematicides provide low to moderate levels of control and are not as effective as conventional nematicides. Biological products can be combined with other cultural practices, such as crop rotation and solarization, for more effective control.

Solarization

The process of trapping the sun's energy to heat soil and inactivate weed seed, pathogens, and pests (including plant-parasitic nematodes) is called solarization. Solarizing soil involves covering an area with clear plastic during the sunniest part of the year and raising soil temperatures to levels that are unfavorable for pathogens and pests. Soil moisture is an important factor in solarization because it helps transfer heat to the target organisms.

Although generally more effective against soil fungi than nematodes, solarization may be an effective strategy to reduce nematode populations without chemicals. Solarization is normally performed for weeks or months at a time. The efficacy is dependent on both time and temperature. In laboratory studies, RKN was killed after 1 hour at 115°F, but accumulation of heat (hours) at temperatures above 100°F was shown to be effective at significantly reducing populations. While high soil temperatures may be difficult to reach in Kentucky, 1 to 4 weeks of solarization conditions should be effective at reducing RKN populations to manageable levels. The time of year, daily temperatures, and hours of sunlight determine the length of solarization needed. Research is ongoing.

Management

Home Garden Options

Crop Rotation

Home gardeners should rotate vegetables from the same crop families to different areas of the garden each year. A rotation schedule that keeps related crops out of the same location for 2 to 3 years is ideal. This management option is most practical in larger garden plots that have more space to rotate crops. Susceptible crops can also be rotated annually with non-host crops such as asparagus, strawberry, or cover crops in order to reduce populations. Including plants such as chrysanthemums, marigolds, or castor beans can suppress RKN development and reproduction. Home gardeners should try to relocate their garden and sow a non-host crop in its previous location when RKN populations are confirmed.

Resistant Varieties

Resistant cultivars of beans, peas, sweet potatoes, and tomatoes are available. Check seed packets or plant labels for information on cultivar resistance.

Early Planting

Early season crops, such as leafy greens and cole (cruciferous) crops, can be planted when soil temperatures are lower and RKN populations are less active. These crops can be harvested before RKN reproduction increases during warmer months.

Sanitation

Home gardeners should inspect transplants and seed pieces prior to planting to ensure that they are not infected with RKN. Regularly clean tools, shoes, pots, and equipment to remove any soil. Infected plants should be removed as soon as possible by digging out the roots and surrounding soil.

Chemical Management

Products for chemical management of nematodes are not available to homeowners.

Additional Resources

- Cleaning & Disinfecting Home Garden Tools & Equipment (PPFS-GEN-17)
https://plantpathology.ca.uky.edu/files/ppfs-gen-17.pdf
- Cleaning & Sanitizing Commercial Greenhouse Surfaces (PPFS-GH-07)
https://plantpathology.ca.uky.edu/files/ppfs-gh-07.pdf
- Home Vegetable Gardening (ID-128)
http://www.ca.uky.edu/agc/pubs/id/id128/id128.pdf
- Soil Solarization for High Tunnels (HORT-7003)
https://www.uky.edu/hort/sites/www.uky.edu.hort/files/documents/solarization.pdf
- Vegetable Production Guide for Commercial Growers (ID-36)
http://www.ca.uky.edu/agc/pubs/id/id36/id36.pdf
- Nematode Suppressive Crops (ANR-856; Alabama Cooperative Extension System)
https://ssl.acesag.auburn.edu/pubs/docs/A/ANR-0856/ANR-0856-archive.pdf
- Soil Fumigant Regulations (University of Georgia)
https://vegetables.caes.uga.edu/external-resources/soil-fumigant-regulations.html

TABLE 1. COMMERCIALLY AVAILABLE CROP CULTIVARS AND THEIR ROOT-KNOT NEMATODE (RKN) HOST STATUS.

	Crop	Species	Cultivars		
			Non-Host[1]	Resistant[2]	Susceptible[3]
Vegetable	**Asparagus**	*Asparagus officinalis*		▪ Atlas ▪ Mary Washington	▪ DePaoli ▪ UC157 F2
	Broccoli	*Brassica oleracea*	▪ Arcadia ▪ Decicco ▪ Liberty	▪ Bonanza	▪ Green Magic
	Carrots	*Daucus carota*		▪ Chun Hong (moderately resistant) ▪ Red Cored Chatney	▪ Amsterdam Minicor ▪ Half-Long Nantes
	Cucumbers	*Cucumis sativus*		▪ Dynasty ▪ Long Green Improved ▪ Marketmore	▪ Dasher II ▪ National Pickling ▪ Poinsett 76
	Eggplant	*Solanum melongena*		*Rootstocks:* ▪ Salutamu ▪ Torpedo	▪ Black beauty ▪ Long green ▪ Round Purple
	Lettuce	*Lactuca sativa*			▪ Ithaca ▪ Penn Lake ▪ V155 ▪ V160
	Onion	*Allium cepa*		▪ Mercury	▪ Cape Flat ▪ Tioga ▪ Vision
	Snap Bean	*Phaseolus vulgaris*		▪ Alabama No. 1 ▪ Kentucky Wonder ▪ Manoa Wonder ▪ Mezcla	▪ Harvester ▪ Rico-23 ▪ Rustproof Golden ▪ Wax
	Spinach	*Spinacia oleracea*		▪ America	▪ America Riccio ▪ Bejo 2592 ▪ Dash ▪ New Zealand ▪ Polka
	Sweet Corn	*Zea mays*		▪ Seneca 110 ▪ Seneca Explorer ▪ Sweet Tooth	▪ Merit ▪ Spancross
	Sweetpotato	*Ipomoea batatas*		▪ Bienville ▪ Bophelo ▪ Evangeline ▪ Murasaki ▪ Okinawa	▪ Centennial ▪ Jewel ▪ Norin-1 ▪ Porto Rico
	Tomato	*Solanum lycopersicum*		▪ Atkinson ▪ Beefmaster ▪ Better Boy ▪ Healani ▪ Nematex ▪ Rossol *Rootstocks:* ▪ Arnold ▪ Estamino ▪ Maxifort	▪ Beefsteak ▪ Money Maker ▪ Roma ▪ Rutgers ▪ Santa Cruz
	Zucchini	*Cucurbita pepo*		*Genotypes* : ▪ Alpha Prime ▪ Patio	▪ Amalthee

Table 1. Commercially available cultivars and their root-knot nematode (RKN) host status (cont'd).

	Crop	Species	Cultivars		
			Non-Host[1]	Resistant[2]	Susceptible[3]
Cover Crops	**Cowpea**	*Vigna unguiculata*	▪ Zippercream	▪ California Blackeye 5 ▪ Colossus ▪ Iron Clay ▪ Mississippi Silver	▪ Chinese Red ▪ UCR779
	Mustard, White	*Sinapis alba*	▪ Abraham	▪ Achilles ▪ Condor ▪ IdaGold	▪ Metex
	Mustard, Brown or Yellow	*Brassica juncea*			▪ Caliente 199 ▪ Nemfix ▪ Pacific Gold
	Oat	*Avena sativa*	▪ Coker 716	▪ IPR Afrodite	▪ Brooks ▪ Coker 820 ▪ Sniper
	Oilseed Radish	*Raphanus sativus*	▪ Boss ▪ Defender ▪ TerraNova	▪ Adagio ▪ Chinese Daikon ▪ Colonel ▪ Comet ▪ Sodbuster	▪ Adios ▪ Daikon-Long
	Red Clover	*Trifolium pratense*		▪ Barduro ▪ Krynia ▪ Southern Belle	▪ Cherokee
	Sorghum	*Sorghum halepense*	▪ SX-17	▪ Cherokee ▪ Northrup King 2660 ▪ Pioneer 8333 ▪ Terral RV 9823	▪ BMR Sweet ▪ DeKalb FS25E ▪ DinaGro GX13662
	Sunn Hemp	*Crotalaria juncea*		▪ K-12 Yellow ▪ Tropic Sun	▪ AU Golden
	Wheat	*Triticum aestivum*		▪ Anza ▪ Lassik *Genotype:* ▪ Rkn3	▪ Nugaines

[1] **Non-host**: RKN is unable to infect or reproduce inside the roots; immune to RKN.
[2] **Resistant**: RKN infection is limited and reproduction is suppressed. Moderate resistance indicates that RKN reproduction is reduced, but not completely.
[3] **Susceptible**: RKN can infect the crop and there is a high level of RKN reproduction.

October 2021

Acknowledgments
The authors would like to thank Dr. Inga Zasada, Plant Pathologist, USDA-ARS Horticulture Crops Research (Corvallis, OR) and Brenda Kennedy, Plant Disease Diagnostician, University of Kentucky, for their reviews of this publication.

Editor: Cheryl Kaiser, Extension Plant Pathology Support
Photos: Rachel Rudolph, University of Kentucky (1); Gerald Holmes, Strawberry Center, Cal Poly San Luis Obispo, Bugwood.org (3,6); Victoria Bajek, University of Kentucky (2,4,5); Jonathan D. Eisenback, Virginia Polytechnic Institute and State University, Bugwood.org (7)