NEMATODE MANAGEMENT

Saad L. Hafez, P. Sundararaj, and Bryan G. Hopkins

Nematodes are minute worm-like animals, able to move between soil particles, between folded leaves of plant buds, in the air spaces of leaves and stems or in plant tissues themselves. The typical nematode is spindle-shaped, unsegmented and bilaterally symmetrical (Fig. 1). Their movement in the soil is influenced by the thickness of the water films surrounding soil particles and they are inactive in dry conditions. Species parasitic on plants all possess a mouth stylet, which they use to puncture plant cells and extract cell contents. Nematode infestation on a potato crop results in tuber yield decline and/or reduction in quality, thereby contributing economic loss to the industry. More than 68 species of plant parasitic nematodes belonging to 24 genera are associated with potato fields from different parts of the world, the four most common in Idaho are root-knot, stubby-root, root-lesion, and potato-rot (Table 1).

Fig. 1. Second stage of root-knot nematodes in the soil.

Table 1. Common potato nematodes, locations, symptoms, and other hosts.			
Name	Predominate Locations Found	Symptoms	Other Hosts
Columbia root-knot (*Meloidogyne chitwoodi*)	Found in abundance, especially in sandy soils.	Knots or galls on the tuber surface. Late-season stunting, chlorosis, wilting, nutrient deficiencies, and secondary diseases (root rots). Localized circles or, in some cases, entire field. Damage can range from slight to over 50% (25% common), with total loss possible due to tuber marketability.	wide range including cereal crops (corn is not a good host)
Northern root-knot (*Meloidogyne hapla*)	Found in abundance, especially in sandy soils.	Symptoms same as Columbia root-knot, however, severity is usually less. Most severe following alfalfa with warm spring conditions (Fig. 2).	alfalfa
stubby-root (*Trichodorus* and *Paratrichodorus* spp.)	Found in isolated sandy soil areas. *P. allius* – found in OR, WA, & CA, while *P. minor* and *P. porosus* found in ID & OR.	Suspect presence when symptoms of corky ringspot appear. Tobacco rattle virus (TRV) infection blemishes are typified by dark brown necrotic tissue in the tuber flesh. These necrotic lesions can take the form of circles, arcs, or diffuse spots; occasionally followed by brown concentric rings on the skin. Tubers infected with TRV may become irregular in shape during early stages of growth and show bud end folding or cracking at harvest. Damage by stubby-root nematodes is greater in wet seasons (Fig. 3 and 4).	wide range including cereal crops
root-lesion (*Pratylenchus* spp.; predominately *P. neglectus* and *P. penetrans*)		Plants in affected areas are weak, chlorotic, stunted and more susceptible to disease. Infected roots turn dark brown to red. Lesions on the tubers are usually shallow. Infection is generally accompanied with early die, characterized by stunted growth, chlorotic foliage, deteriorated roots, premature senescence, and reduced yields (Fig. 5).	
potato-rot (*Ditylenchus destructor)*	Not widely present in Idaho, but has been found in isolated fields in the eastern part of the state.	Entrance in tubers is through lenticels and symptoms start as small whitish regions in the cortex, present during early and mid season tuber formation detected by removing the peel. The lesions coalesce, as severity increases, and the affected tissue darkens gradually through grayish to dark brown color. The tuber skin may remain intact but exists as a papery thin membrane over the lesions or may crack as a result of stress in	wide range: especially snap beans; red clover and corn are intermediate (alfalfa

		the tuber. Affected tissues are soft and mealy. The effect of nematodes will manifest itself at harvest or storage when infected tubers begin to rot progressing to sunken dark colored pits marking the surface and skin cracks. Subsurface tissue will develop a brown, matted wool-like appearance (Fig. 6).	is a poor host and oats are a non-host); also many weeds and even fungi

MANAGEMENT OPTIONS (Table 2.)

Root-knot nematode

Temik® offers valuable suppression of root-knot nematode species. If root-knot nematode is a severe economic pest, the use of other nematicides or fumigants such as metam sodium, Telone II®, or Mocap® should also be employed. In recent University of Idaho studies in root-knot infected fields, maximum percentages of U.S. No. 1 tubers occurred in plots treated with Vydate® and Mocap®. Further it was found that application of Mocap® either during fall or spring (2 or 1.5 gall) along with Vapam® (40 gal) significantly reduced the nematode infested potatoes as compared to untreated potatoes.

Recent research has explored the use of cover crops as part of a control strategy for root-knot nematodes. Experiments conducted at micro plot and field level confirmed that rape seed 'Humus' and oil radish '*Raphanus sativus*' reduced *M.chitwoodi* population and increased the potato tuber yield (106-185%) and quality under Idaho conditions. Improved efficacy may result from the identification of a rotation crop that is resistant to or a non host for the nematode species. Utilization of such resistant rotation crop varieties can reduce nematode survival thereby reducing nematode damage and increasing yield potential.

Fig. 2. Symptoms of root-knot nematode infected tubers.

Stubby-root nematode

Stubby root nematodes adapt to unfavorable conditions by migrating downward in the soil. For this reason they are persistent and very difficult to control. Since several generations can be produced within a year, large populations of stubby-root nematodes can develop quickly. Their numbers can also decline rapidly after the crop is removed, so sampling at peak population times is critical for getting a good representation of population density. They may survive cold winters by migrating below the frost line and going dormant.

Control of stubby root nematodes requires consistent application of multiple chemicals with nematicidal activity. It is common for fields with heavy infestations to be fumigated in the fall with metam sodium, again in the spring with Telone II®, and then have an application of a nematicide at planting. Temik® is an effective product for controlling stubby-root nematode. Temik® moves up and down in the potato hill with the waterfront, reaching nematodes as they move in the soil. Temik's systemic activity also kills nematodes as they feed on the root system

of potato plants. These combined factors make Temik® the effective chemical for controlling stubby-root nematode populations. Efficacy of the nematicides on stubby rot nematode differs with respect to their application method in the field. In recent studies, Temik® applied in-furrow at planting, modified in-furrow at planting or in-furrow at planting in combination with foliar applications of Oxamyl resulted in the lowest incidence of corky ring spot disease and produced the highest total and marketable yields. Further, it was found that Temik applied in front of the shoe at planting tended to be less effective than other placements of Temik.

Control of stubby root nematodes is very expensive, often exceeding $300 per acre. The best control for this disease is the use of resistant varieties. Breeding efforts have led to the development of new russet type varieties with good resistance to this disease. These varieties may soon be available for public use.

Fig. 3. Internal symptoms of corky ringspot are concentric rings and diffuse spots in the flesh.

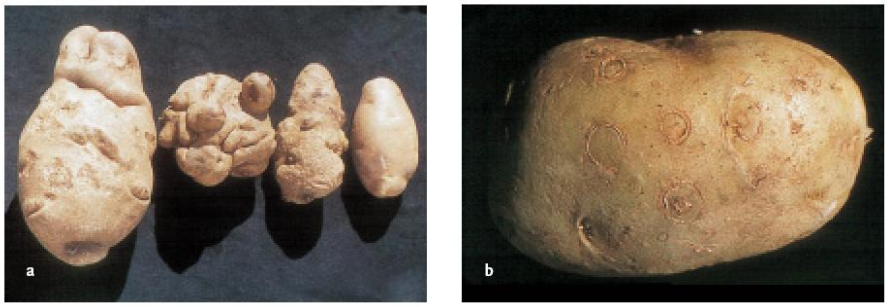

Fig. 4. External symptoms of corky ringspot include irregular shape and cracking (a) and arc-shaped lesions in the tuber skin (b).

Root-lesion nematode

Planting of a green manure crop prior to potatoes is an effective way for the management of nematodes under field conditions. Green manure crops of oil radish and barley result in decline

of *P. neglectus* population densities and increased tuber yield. In addition, application of prophos® along with green manure has been shown to significantly increase tuber yield.

Fumigation with metam sodium or Telone II® is usually effective against lesion nematodes. Growers that fumigate should sample for nematodes following fumigation (at least three weeks after fumigation) but prior to planting and may use Temik® to reduced nematode populations if they remain high. Temik® applied at planting remains in the root system and soil profile for 6-8 weeks. When eggs hatch, this long residual results in nematode exposure and subsequent control.

Temik® is a systemic product that is highly effective in controlling root-lesion nematode that feed inside the root system. Research at University of Idaho shows that controlling root-lesion nematode populations has a positive impact on tuber yield. Twenty pounds of Temik® applied at planting significantly reduced root-lesion populations and increased tuber yield an average of 38 cwt/A. Years of research and grower experience along the Snake River Plain of Southern Idaho have also proven that Temik® applications often result in early die suppression with accompanying yield response. These results may be due to several positive effects caused by Temik® including; lesion nematode control, reducing the development of Verticillium microsclerotia, or plant growth regulator effects.

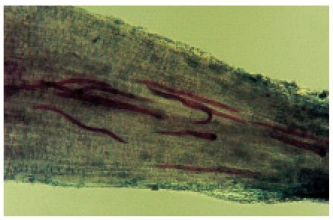

Fig. 5. Lesion nematodes within a potato root.

Potato-rot nematode

Once established in a field, potato-rot nematode can survive on fungi or weed hosts and will remain in the soil. They cannot survive extended periods of drought or low soil moisture (< 40%). High relative humidity is an essential factor for the establishment of this nematode.

Prevention of introduction into new fields is the best control method for potato-rot nematodes. Use of healthy seed material is the primary step to avoid infestation with *D. destructor,* since *D. destructor* has a wide host range and historically crop rotation has not been considered a viable control option. However, crop rotation can be effective when used in combination with sanitary procedures and the use of labeled nematicides on the rotation crop.

Fig. 6. Potato-rot nematode infected tubers.

Table 2. Chemical and non-chemical controls for potato nematodes.											
Common potato nematodes	Fumigants				Non-Fumigants					Other Forms of Control	
	----------True----------			Non-True	Contact		Systemic			Biological	Green Manures
	Methyl 1,3-D,	1,3 dichloropropene + chloropicrin (Telone C-17®)	1,3 dichloropropene	metam-sodium (Busan®,	ethoprop	MITC	aldicarb (Temik®)	Vydate®	Nemacur®	Myrothecium verrucaria strain AARC-0255 (DiTera WDG®)	
Columbia root-knot	E	E	E	E	E	E	E	E	E	E	rape seed 'Humus' and oil radish '*Raphanus sativus*'
Northern root-knot	E	E	E	E	E	E	E	E	E	E	
stubby-root	E	E	E	E	E	E	E	E	E	E	
root-lesion	E	E	E	E	E	E	E	E	E	E	oil radish, barley
potato-rot	E	E	E	E	E	E	E	E	E	E	

GENERAL STRATEGIES FOR MANAGING NEMATODES

Green Manures

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Oilseed mustard and white radish have shown excellent results for nematode control when used as a green manure trap crop. In addition to reducing soil densities of nematode population, other benefits of using green manure trap crops include increased yields of subsequent potato crops, improved soil tilth and water holding capacity, reduced nitrogen leaching into groundwater, weed suppression, reduced soil erosion, and potential suppression of diseases.

Fumigation

Fumigation not only suppresses nematodes, but can also provide secondary pest control. For example, they can help suppress disease organisms such as *Verticillium dahliae*, which can improve potato quality and yield. Fumigation also controls weeds and soil insects present in the treated zone. Telone II® is recognized for its ability to help control plant parasitic nematodes, deep rooted perennial weeds, and soil inhabiting insect pests. Metam-sodium products are recognized as being most effective in suppressing Verticillium wilt, increasing yield and quality and in suppressing plant parasitic nematodes and annual weeds.

Soil moisture is the most important factor for achieving the desired pest control through soil fumigation. Excess moisture acts as a vapor barrier to prevent proper movement of the gaseous true fumigants. On the other hand, if there is not enough moisture around the soil particles to absorb the fumes, the fumigant escapes from the soil too quickly. Non-true (biocide) fumigants are extremely water-soluble and move easily through the soil solution and, during the final stage of conversion to a gas, will move in similar fashion to that of a true fumigant.

Excessively high soil temperature speeds gaseous diffusion, thus shortening the exposure of pests to toxic fumes and results in poor control and more crop damage. Higher soil temperatures also increase the rate of conversion of Telone II® to a gaseous state and metam-sodium to MITC. Low soil temperature increases the retention of the gas, thus prolonging exposure of pests to toxic fumes and resulting in more effective control and less crop damage.

Clay soils tend to restrict movement of all types of fumigants and although clay soils slow the conversion of Telone II® to the gas phase, they actually increase the rate of metam-sodium conversion to MITC, the liquid biocidal state. In fine-textured clay soils, pore spaces are much smaller than those in sandy or sandy-loam soils. Such small pores are likely to be blocked by excess moisture or compaction, resulting in non-continuous passages through which vapors are unable to diffuse. As a consequence, fumigation may be incomplete, especially if the compound is highly volatile or short-lived in the soil, but a surface seal, which is necessary to prevent rapid loss of vapor, is more difficult to obtain with coarse-textured soils.

The following are general application guidelines that will help improve fumigant effectiveness, however, always follow label instructions.

*Incorporate crop residues into the soil and allowed to decompose before fumigant is applied.

*Minimize previous crop residues and thoroughly chop and incorporate deep into the soil profile.
*Allow for sufficient time for decomposition of previous crop residues (several weeks for most crops and several months for alfalfa and corn).
*Test soil for adequate nitrogen (at least 40 lb./ac.) to add in decomposition of previous crop.
*Till surface foot of soil to insure that it is free of clods before chemical is applied.
*Break apart subsurface plow-pans with deep tillage/ripping.
*Insure that soil moisture is relatively dry for application of true fumigants (1/2 field capacity for clay soils to just below field capacity for sands) and quite moist for non-true fumigants (70-80% Plant Available Water).
*Insure that soil temperature 8 inches below the soil surface is between 45 and 85°F (optimum is 70-80°F).
*Broadcast apply fumigant (preferable method) at a depth of 6 to 15 inches or band apply at a depth of 10 to 18 inches, increasing in depth as dosage increases.
*Apply fumigant early in the fall. Effectiveness and crop safety are reduced with spring fumigation in the Pacific Northwest.
*Seal the soil with a disk and drag or roller harrow following the injection equipment.
*Avoid disturbing the soil for at least three weeks, or approximately 1 day for every gallon of true fumigant applied per acre.

Comment [BH2]: insert link to irrigation chapter discussion of field capacity or bring up a little definition with a click of the mouse.

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Increase in fumigant rate may be necessary for the following:

*High soil organic matter
*High clay percentage
*Following a perennial crop (e.g. alfalfa or grass pastures)
*High soil pH (metam-sodium only)
*High soil test levels of Cu, Fe, and Mn (metam-sodium only)
*High populations of nematodes
*Presence of Columbia root knot nematodes

SAMPLING FOR NEMATODES

Time of sampling

Sampling should be done before any treatment or management decision is made and before planting. Soil should be moist but not waterlogged or frozen. The best time for nematode sampling is usually before harvest (early fall) in fields of rotations crops preceding potatoes.

Field mapping

Since the distribution of nematodes is seldom uniform the field to be sampled should be subdivided and mapped. Any observable variation in previous crop growth, soil texture, moisture and draining patterns, or cropping history will constitute a subdivision. One sample may be used to represent up to five acres of a uniform field subdivision as determined by mapping. Each sample should contain at least 4 cores per acre. A good approach in sampling is to bulk the soil cores in a clean bucket, mix thoroughly, and sub-sample and submit one quart of the mixture for analysis. Place the sample in a sturdy, moisture-retaining bag and clearly identify with a tag

attached to the outside of the bag. Tags or labels inside the bags may get wet and discolored easily.

Where to sample

Soil samples should be taken from the primary plant root zone. If the crop has not been planted, take samples to match the root zone of the intended crop. If the crop is already planted, samples should be taken from the plant parts showing symptoms. Soil or plant samples should be taken from problem areas showing symptoms and from unaffected areas for comparison. Before planting potatoes, sample cores from a fallow field should be taken by first removing the upper two inches of soil, and then sampling to a depth of 15 to 20 inches. Deeper cores, up to 30 inches, should be taken after prolonged fallow, dry or freezing conditions.

Equipment for collecting soil samples for nematode assays includes shovels, soil augers or tubes and motorized samplers. The typical cylindrical tube sampler designed by soil scientists serves as the standard equipment. Include name, location, soil type and texture, observable symptoms (yellowing, necrosis, root rotting, galling, wilting, etc.), cropping history (past several years, current, anticipated) and date of last treatment with a nematicides. This information is valuable for diagnosis and identification of nematode problems.

Storage and delivery

Even the most carefully taken samples may yield inferior results if not stored and delivered properly. Keep the sample cool, ideally 50 to 55^{o} F. Do not leave the sample in direct sunlight, a vehicle or in other areas that may become hot. Do not freeze. An insulated cooler is convenient for sample protection. Deliver or mail the sample immediately to the processing laboratory. Use First Class, UPS, Greyhound or other express delivery and pack well in a sturdy cardboard box or coffee can. REMEMBER – Samples must be clearly labeled and accompanied by complete background information. Diagnostic services are available at the University of Idaho - Parma Research and Extension Center, Parma, ID 83660. Telephone: (208) 722-6701.

Trade names are provided for clarity and do not constitute an endorsement of the product.