How Nematodes Cause Disease in Plants

Interactions With Other Plant Pathogens

H = Host
P = Pathogen
N = Nematode

→ Direct effects
--- → Indirect effects
How Nematodes Cause Disease in Plants

Interactions With Other Plant Pathogens

H = Host
P = Pathogen
N = Nematode
E = Environment

------> Direct effects
-----> Indirect effects
Interactions Between Nematodes and Plant Pathogens

Direct Effects

- Some fungi attack and destroy fully formed giant cells and decrease population densities of root-knot nematodes.

- *Bursaphelenchus* feeds directly on blue stain fungus (*Ceratysistis*). Don’t know effect on fungus.

- Microbial-feeding nematodes which feed on the pathogen, some fungal feeding nematodes have been shown to reduce root-rot infections by feeding on the fungal pathogen.
Interactions Between Nematodes and Plant Pathogens

- Interactions known since 1892
- Several have been described (see handout Table 9.1)
- Can be important aspect of disease
- Relationships complex, mechanisms poorly understood
- Results often vary from study to study
- Still debate on how important these are in the field

- Several interactions cause symptoms that do not exist with either pathogen alone or disease severity may be much more than additive = synergistic – i.e. 10% (n) + 10% (p) => 50% (n+p)!
Interactions Between Nematodes and Plant Pathogens

1. Nematode aids in transmission of plant pathogen
   A. Pathogen requires introduction into healthy tissue
      = “virus vectoring”

1958 *Xiphinema index* demonstrated to transmit grape fanleaf virus = first known nematode vector.

Over 20 viruses are now known to have nematode vectors and more are suspected.

Only Dorylaimida & Triplonchida have virus vectors!
= Class Enoplea
Nematode Virus Vectors

Dorylaimida: *Longidorus, Paralongidorus, Xiphinema*

Triplonchida: *Trichodorus, Paratrichodorus*

Not all species in these genera have been demonstrated to be virus vectors.

See handout for species and virus associations.

*Longidorus & Xiphinema* transmit "NEPO" viruses => polyhedral shaped. *(nematode polyhedral).*

*Trichodorus and Paratrichodorus* transmit "TOBRA" viruses => tubular or rod shaped. *(tobacco rattle)*

A nematode that carries a virus is said to be "viruliferous". Only part of the population has virus.
Nematode Virus Vectors

Transmission and Retention
Very little evidence of any pattern in specificity.

Several nematode species transmit the same virus isolate. A single nematode species may transmit several viruses.

Other associations are very specific with different strains of a virus requiring different nematode species as vectors.

(For example, Scottish and English strains of raspberry ringspot virus are transmitted by different species of Longidorus.)
Nematode Virus Vectors

Transmission and Retention
Nematodes acquire virus when they feed at the root tip of infected host plants.

Adult and juvenile stages are equally efficient in acquiring virus in short feeding periods of an hour or less (sometimes less than 5 minutes).

Virus may persist in the nematode longer than in vitro but do not multiply while in nematode.
Nematode Virus Vectors

Transmission and Retention
NEPO virus, and probably TOBRA viruses too, are not retained through a molt and do not pass to the egg.

This suggests that virus is retained extracellularly within the nematode or on some part or tissue that is shed during molting.

Most Longidorids => inner surface of odontostyle
L. elongatus => inner surface of stylet guiding sheath
Xiphinema => cuticular lining of the esophagus from anterior of the odontophore (extension) to the intestine.
Trichodorus => cuticular lining throughout the esophagus & stoma?
Nematode Virus Vectors

Sites of Virus Retention

Xiphinema spp.  L. elongatus  L. macrosoma  Trichodorus or Paratrichodorus

C.E. Taylor
W.M. Robertson
Nemapix 1
Nematode Virus Vectors

Transmission and Retention
Viruses are absorbed to these surfaces during feeding as plant sap containing virus passes through.

Other nontransmittable plant viruses apparently will not stick here => specific association exists between the protein coat of the virus and the cuticular surface in the nematode.

Dissociation of virus from nematodes seems to occur when saliva passes from nematode into the plant cell during initial stages of feeding.
Nematode Virus Vectors

Dissociation
Dissociation may be due to pH or ionic changes of surface charge on virus coat, some enzymatic effect of the saliva either on the cuticular surface, on the virus coat, or on materials involved in the binding.

Some virus strains may be retained but are not released.

Dissociation takes place slowly with nematode losing a few virus particles at a time over many weeks in succession.
Nematode Virus Vectors

Dissociation

Adult *Xiphinema* and *Trichodorus* may remain vectors for their entire life while *Longidorus* appears to lose their ability to transmit virus after a time (about 8 weeks).

So viruses obtained from a single feeding event on a virus infected plant can be transmitted to several adjacent uninfected plants as these migratory ectoparasites move around.

Apparently the plant cell must not be severely damaged by the nematode if virus is to infect plant successfully.
Black Line at Graft Union
Caused By Tomato Ringspot Virus
Vectored By Dagger Nematode
Unthrifty Pear Tree with Tomato Ringspot Virus
Grape Fan leaf Virus
Vector = *Xiphinema index*
Arabis Mosaic Virus in Strawberry
Vector = *Xiphinema diversicaudatum*

C. Hogger
Raspberry Ringspot Virus on Cherry
Vector = *Longidorus macrosoma*
Raspberry Ringspot Virus on Raspberry
Vector = *Longidorus* sp.?
Symptoms of Corky Ringspot Disease

- Necrotic Arcs
- Diffuse Spots
Interactions Between Nematodes and Plant Pathogens

1. Nematode aids in transmission of plant pathogen
   A. Pathogen requires introduction into healthy tissue = “virus vectoring”
   B. Pathogen requires access to susceptible tissue

Nematode is essential.
Inoculum is carried externally (primarily bacteria but also some fungi which have special attachments on the spores)

Important for pathogens of apical meristems which need some way to get to these tissues.

See examples listed on handout.
Corynebacterium fascians requires Aphelenchoides spp. to reach meristem of strawberry.

Bacteria causes "stunting" of leaf blades; nematode causes "twisting" of leaf blades => plant appears like cauliflower => death of crown.
In Australia, *Anguina lolii* assists the invasion of ryegrass by *Corynebacterium ratheyi* which produces a toxin that is fatal to sheep, horses and cattle. A rancher can suddenly lose 100's of sheep in one day to poisoning from this relationship.
Interactions Between Nematodes and Plant Pathogens

1. Nematode aids in transmission of plant pathogen
   A. Pathogen requires introduction into healthy tissue = “virus vectoring”
   B. Pathogen requires access to susceptible tissue
   C. Nematode facilitates access of pathogen

Nematode is not essential. “Action is on pathogen”
Other pathogens may also be passively carried into plant tissues on the cuticle of nematodes.
In addition, some bacterial pathogens can be carried into plant tissues within the gut of bacterial-feeding nematodes. This can happen when bacterial feeders enter lesions to feed on bacteria that may be colonizing necrotic tissue. See examples on handout.
Interactions Between Nematodes and Plant Pathogens

1. Nematode aids in transmission of plant pathogen
2. Nematode assists the ingress of the pathogen
   = “Secondary Invasion”
   “Action by nematode is on plant”
   A. Pathogen is aided by wound in plant tissue
   = wounds alone may assist some bacterial and fungal pathogens.
   Several bacterial wilts are increased in hosts which have been mechanically wounded or wounded by nematodes (eg. Carnation wilt, tobacco wilt, raspberry crown gall).

Also suspected mechanism for some nematode-fungus interactions in root-rot & vascular wilts.
Interactions Between Nematodes and Plant Pathogens

1. Nematode aids in transmission of plant pathogen
2. Nematode assists the ingress of the pathogen
   =“Secondary Invasion”

   Action by nematode is on plant

A. Pathogen is aided by wound in plant tissue
B. Pathogen benefits from modification of host substrate due to changes in host physiology caused by the nematode.
Interactions Between Nematodes and Plant Pathogens

B. Pathogen benefits from modification of host substrate due to changes in host physiology caused by the nematode.

Nematode provides favorable substrate for the establishment of the pathogen. In many relationships the wound alone is not sufficient.

1. Changes in substrate may be "localized" at or near the site of nematode attack (necrotic lesions, giant cells, galls, etc.) and serve as starting point for pathogen (i.e. foodbase).

See examples on handout.
Species of *Pratylenchus* which cause *necrotic lesions* appear more important than those which do not and may be the reason why only some species of *Pratylenchus* cause a *synergistic interaction* with *Verticillium* to increase the severity of early dying in potatoes.

Levels of *fungal toxin* developed by *wilt pathogens* are dependent on levels of certain *nutrients* in the host, which may be increased by nematode infection.
B. Pathogen benefits from modification of host substrate due to changes in host physiology caused by the nematode.

Nematode provides favorable substrate for the establishment of the pathogen.

2. Changes in substrate may be "systemic" due to changes in host physiology caused by the nematode so that sites remote from the nematode become more susceptible to attack by the pathogen.

Has been demonstrated in "split-root" studies.

See examples on handout.
Interactions Between Nematodes and Plant Pathogens

B. Pathogen benefits from modification of host substrate due to changes in host physiology caused by the nematode.

Nematode provides favorable substrate for the establishment of the pathogen.

3. In some cases favorable effects may extend outside the host into the soil. => "pathogen-favoring" exudates.

Meloidogyne -Rhizoctonia-tomato root rot example
Interactions Between Nematodes and Plant Pathogens

1. Nematode 
   aids in transmission of plant pathogen
2. Nematode 
   assists the ingress of the pathogen
3. Nematode 
   breaks plant resistance to pathogen

= continuum

Mechanism is not always understood, nematode may disrupt some natural defense mechanism of the plant against the pathogen such as altering cell permeability.

A. Normally disease resistant cultivars become susceptible when infected with nematodes
   => usually *Meloidogyne.*
Interaction of *Meloidogyne incognita* and *Fusarium* on Cotton.

Control  Nematode  Fungus  Fungus

N.A. Minton  Nemapix 1
Meloidogyne incognita and Fusarium oxysporum on wilt-tolerant tomato

Control  Nema Alone  Fungus Alone  Nema+Fungus
Interaction of Three *Meloidogyne* Species and *Fusarium solani* on Chrysanthemum Fungus added 3 Weeks After Nematode
Interactions Between Nematodes and Plant Pathogens

1. Nematode aids in transmission of plant pathogen
2. Nematode assists the ingress of the pathogen
3. Nematode breaks plant resistance to pathogen
   = continuum

B. Normally susceptible cultivars show acceleration or intensification of infection and damage by pathogen.
Meloidogyne incognita and Fusarium oxysporum on wilt-susceptible tomato
Interactions Between Nematodes and Plant Pathogens

1. Nematode aids in transmission of plant pathogen
2. Nematode assists the ingress of the pathogen
3. Nematode breaks plant resistance to pathogen
   = continuum

C. Nematode infection allows "nonpathogens" to become pathogenic.

"Disease" is caused by microorganisms that are not generally considered to even be facultative parasites but become so because of extensive and complex changes in host physiology caused by Meloidogyne. Trichoderma harzianum causes damage to tobacco only when M. incognita is present.
Interactions Between Nematodes and Plant Pathogens

1. Nematode aids in transmission of plant pathogen
2. Nematode assists the ingress of the pathogen
3. Nematode breaks plant resistance to pathogen
4. Interactions between nonparasitic nematodes and plant pathogens (p. 75? - where?)

A. Beneficial to the pathogen
   Dispersal, protection while in gut

B. Detrimental to the pathogen
   Direct feeding on pathogen by fungal or bacterial-feeding nematodes
How Nematodes Cause Disease in Plants
Detrimental Effects on Beneficial Plant Symbionts

Effects of nematodes on plant health include more than direct causes of disease.
1. **Rhizobia**

"Detrimental effects"

Disturbances in plant host caused by nematode infection can interfere with adequate colonization of legumes by rhizobia.

Relationships between plant-parasitic nematodes and rhizobia can be very specific, for example, 1 race of *Heterodera glycines* depressed nodule formation on soybean more than 3 other races tested.

Clover cyst (*Heterodera trifolii*) and root-knot (*Meloidogyne javanica*) nematodes reduced nodules on white clover.
1. **Rhizobia**

   "**Detrimental effects**"

   Nematodes actually showed **preference for nodules** as infection sites. => earlier disintegration of nodules & depriving plant of **N** normally obtained through the symbiosis.

   "**Beneficial effects**"

   Bacterial-feeding nematodes migrate around the rhizosphere and **distribute** *Rhizobium* cells over more of the root surface and thus benefit the plant.
2. Mycorrhizae
Many plants are dependent on adequate mycorrhizal colonization to grow normally.

Interactions between nematodes and mycorrhizae represent another very complex set of relationships that appear dependent on the particular study conditions.

Many plant-parasitic nematodes reduce the amount of benefit obtained from mycorrhizal infection but the extent of these responses vary along a continuum from little effect to almost completely blocking mycorrhizal establishment.
2. Mycorrhizae
Different species of nematodes affect the mycorrhizal relationship differently.

Nematodes may decrease the amount of nutrients taken up by mycorrhizae or alter ability of mycorrhizae to protect the plant from other pathogens.

Fungal-feeding nematodes may feed directly on mycorrhizae and reduce their benefit.

In one study, this reduced P uptake by a legume to an extent that there was insufficient P for successful nodulation, thus both N and P nutrition to the plant were affected.
2. Mycorrhizae

**In general**: mycorrhizal plants grow less well if they are infected with nematodes, but this still may be better than a plant without either nematodes or mycorrhizae, particularly if the plant is mycorrhizal dependent.

\[ P_N < P < P_{MN} < P_M \]
Effects of Plant Pathogens on Nematodes

Detrimental Effects

Pathogen may impair nutrition for nematodes or produce harmful byproducts which reduce the rate of growth of the nematode population, often difficult to know what mechanism is.
Effects of Plant Pathogens on Nematodes

Detrimental Effects

- Inhibit hatching
  \((Pyreno\text{ch}a\text{e}ta \text{l}ycopersici & \text{G}lobodera)\)

- Inhibit giant cell formation
  \((Pyreno\text{ch}a\text{e}ta \text{l}ycopersici & \text{G}lobodera)\)

- Damage fully formed giant cells
  \((\text{Fusar}i\text{u}m, \text{Phytop}h\text{th}o\text{r}a \text{a}nd \text{some} \text{bacteria} & \text{M}eloidogyne)\)

- Reduce reproduction rate
  \((\text{Fusar}i\text{u}m & \text{Pratylench}u\text{hus})\)
Effects of Plant Pathogens on Nematodes

Beneficial Effects
- Roots become more attractive to nematodes - due to exudates or CO$_2$.
  \textit{(Trichoderma viride and Fusarium oxysporum (takes more) \& Pratylenchus penetrans)}

- Increases reproduction = breaks resistance to nematodes
  \textit{(Verticillium dahliae \& Pratylenchus)}
  \textit{(Fusarium \& Heterodera glycines on soybean)}
  \textit{(Fusarium and Rotylenchulus reniformis on pea)}
  Blue stain fungus \textit{(Ceratysistis)} = alternative food source for \textit{Bursaphelenchus}. 
Interactions Between Nematodes and Plant Pathogens

Conclusion

Nematode-pathogen interactions are very difficult to study because they are a dynamic relationship, which may change as relationship progresses.

Can get conflicting results from different studies if comparisons are not made carefully i.e. different growing conditions or length of study may suggest different effects of relationship.

Timing of the introduction of nematodes and other pathogens in a study can influence type of interaction observed.
Effects of Other Plant Stresses On Nematode Diseases of Plants

Before we leave the discussion of how nematodes cause disease in plants it is important to consider how other abiotic or biotic stresses may affect the host-parasite relationship, the severity of disease and the response to control.

Many plants can tolerate moderate densities of nematodes if they are not stressed by other factors.
Effects of Other Plant Stresses On Nematode Diseases of Plants

Plants may be subjected to a number of stresses simultaneously.

Multiple stresses may be additive or synergistic.

The response of a stressed plant to nematode infection or to relief from that infection through nematode control can be very complex depending on the nature of the other stresses and how they may interact with the nematode and the plant host.
Effects of Other Plant Stresses On Nematode Diseases of Plants

A plant which is water stressed in a well-drained soil may be more damaged by nematodes than a plant growing in soil that retains more water even if the nematode populations are the same.

A plant which is also stressed by another pathogen in a synergistic interaction with a nematode may respond dramatically to nematode control and alleviate symptoms of what may appear to be a fungal disease which might not be as easy to control.
Effects of Other Plant Stresses On Nematode Diseases of Plants

A plant which is nutrient stressed in addition to being attacked by nematodes may not respond as well as expected to nematode control if the nutrient limitations are not also corrected.

Furthermore, a plant under simultaneous stress of nematodes and low fertility or low pH may respond more to fertilizer or lime than to a nematicide.
Many plants that are resistant to nematodes lose that resistance at high temperatures. During unusually warm growing seasons plants may exhibit much more nematode damage than anticipated.

Thus, we must always consider the entire health of the plant when assessing plant disease, whether that disease appears to be caused by nematodes or not.