Nematode Management on Food Crops in Hawaii

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Nematode: A Hidden Pest

Crop losses of banana due to plant-parasitic nematodes:

Costa Rica	30-50%
Panama	30-50%
India	30-60%
Ghana	56%
Uganda	58%
Nigeria	90%

(Speijer and Fogain, 1999)

Perspective of Nematode Damage

Estimated soybean yield loss (bushels) in the United States due to diseases during 1996-2010

	1996	2000	2006	2010
Bacteria	772,000	378,000	3,731,000	6,377,000
Viruses	2,392,000	37,277,000	7,451,000	3,547,000
Fusarium	1,232,000	1,590,000	6,215,000	10,627,000
Sudden death syndrome	3,709,000	75,764,000	27,320,000	70,088,000
Root-knot nematodes	5,917,000	3,662,000	7,919,000	7,556,000
Soybean cyst nematodes	213,862,000	141,967,000	123,778,000	118,129,000
U.S. Soybean harvested	400,297,000	398,656,000	401,593,000	478,298,000

http://aes.missouri.edu/delta/research/soyloss.stm

Perspective of Nematode Damage

Healthy tomato roots.

Root-galls caused by root-knot nematodes on tomato

Picture: A. Loffredo

Introduction

In general, nematodes account for an estimated 14% of all worldwide plant losses, which translates into almost $100 billion dollars annually.

Key Plant-parasitic Nematodes in Hawaii

- Types of plant-parasitic nematodes
- How to take soil samples
- Nematode Management Options
- Good nematodes

Types of Nematode
(Categorized by infection points)

- Sedentary endoparasitic nematodes
- Semi-endoparasitic nematodes
- Migratory endoparasitic nematodes
- Ectoparasitic nematodes
- Foliar nematodes

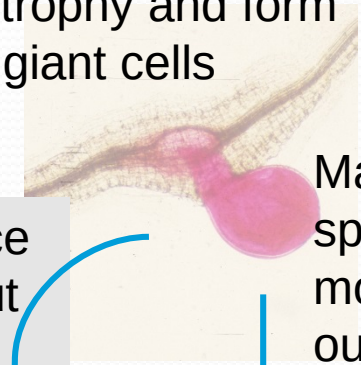
Sedentary Endoparasitic Nematodes

Root-knot nematode (Meloidogyne spp.)

J2
(move inside root tissues until a feeding site is found)

J3-J4
(sausage shape)

Feeding site undergoes hypertrophy and form giant cells

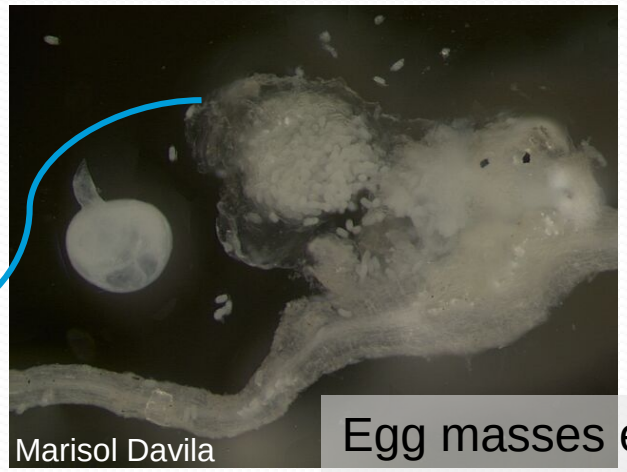


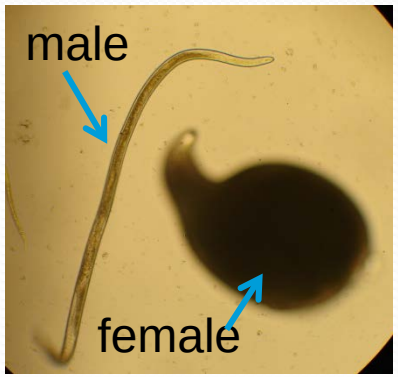
Male spends most time outside of the roots

Root-knot nematodes can produce eggs parthenogenetically (without sexual reproduction)

J2
(infective stage)

egg



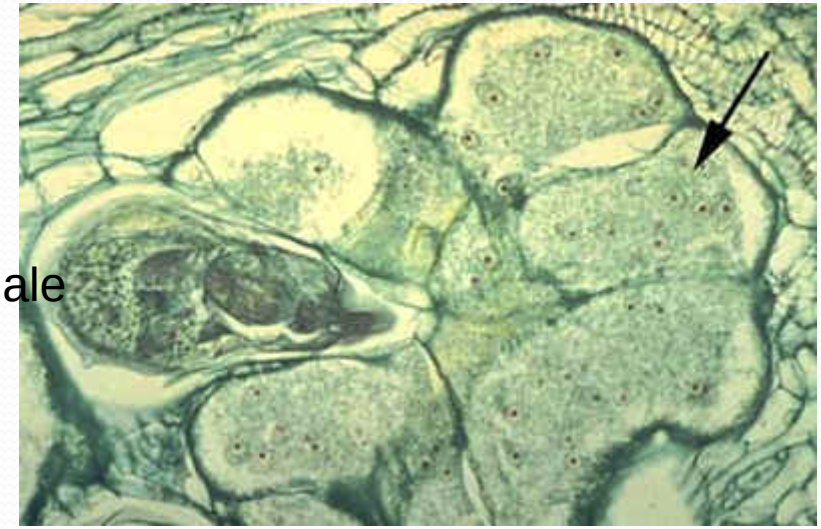


Egg masses erupt from root galls

Giant cells

= enlarged, multinucleate cell formed in roots by repeated nuclear divisions without cell wall formation, this phenomenon is known as hypertrophy. It is induced by secretions of root-knot nematodes.

Giant cell



Root-knot female

This lead to swollen of roots, thus forming root galls or root knots.

Picture: Society of Nematologists

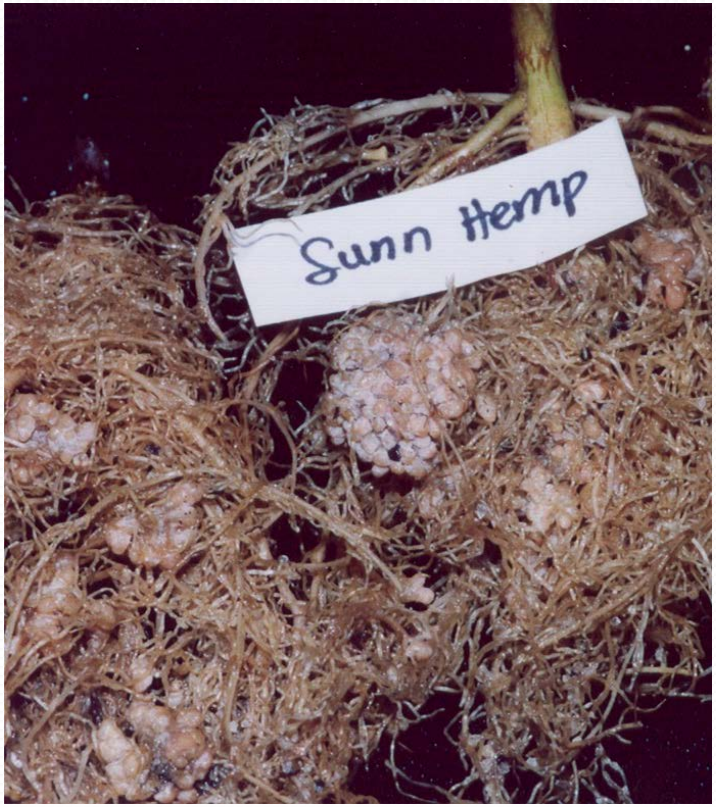
Root Galls formed by Root-knot Nematodes

Severe root galling, loss of functional/feeding roots, plant will wilt.

Picture: Koon-Hui Wang

Not to confuse root galls from root nodules

- Rhizobium = Symbiotic N fixing bacteria on leguminous crops
- Legume nodules harbor an iron containing protein called legheamoglobin, which make the nodule redish in color. It facilitates the conversion of nitrogen gas to ammonia.



Root-knot Nematodes cause Unmarketable Produce

Split roots of carrot caused by root-knot nematodes.

Blemishes on cross section of a potato tuber infected by root-knot nematodes.

Infection of root-knot nematodes results in unmarketable potato tuber

Picture: Society of Nematologists

Symptom of Root-knot Nematode Damage can be above and below ground

Kona coffee root-knot nematode causes coffee decline, results in severe economic yield loss to coffee production in Hawaii.

Wilting

Swollen tap root

On some crops, root gall symptom is not obvious.

Swollen coffee root with few feeder roots

Pictures by M. Serracin

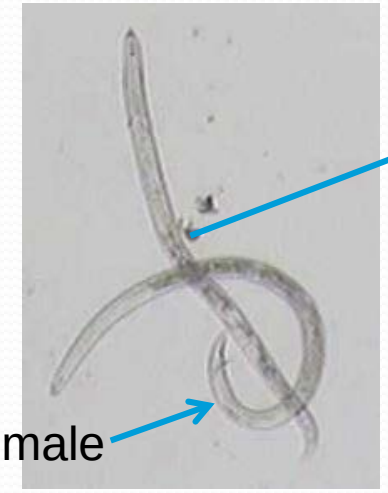
Semi-endoparasitic Nematode

Reniform Nematode (Rotylenchulus reniformis)

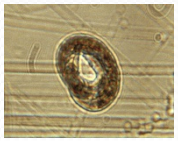
Pre-adult female

slightly swollen

Kidney-shape female

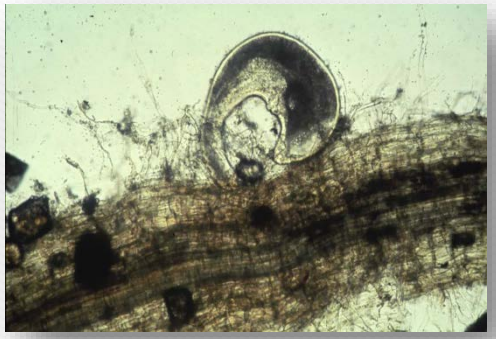


male



anhydrobiosis

Difficult to manage (can survive in dry fallow soil for years)



egg

J2

J3

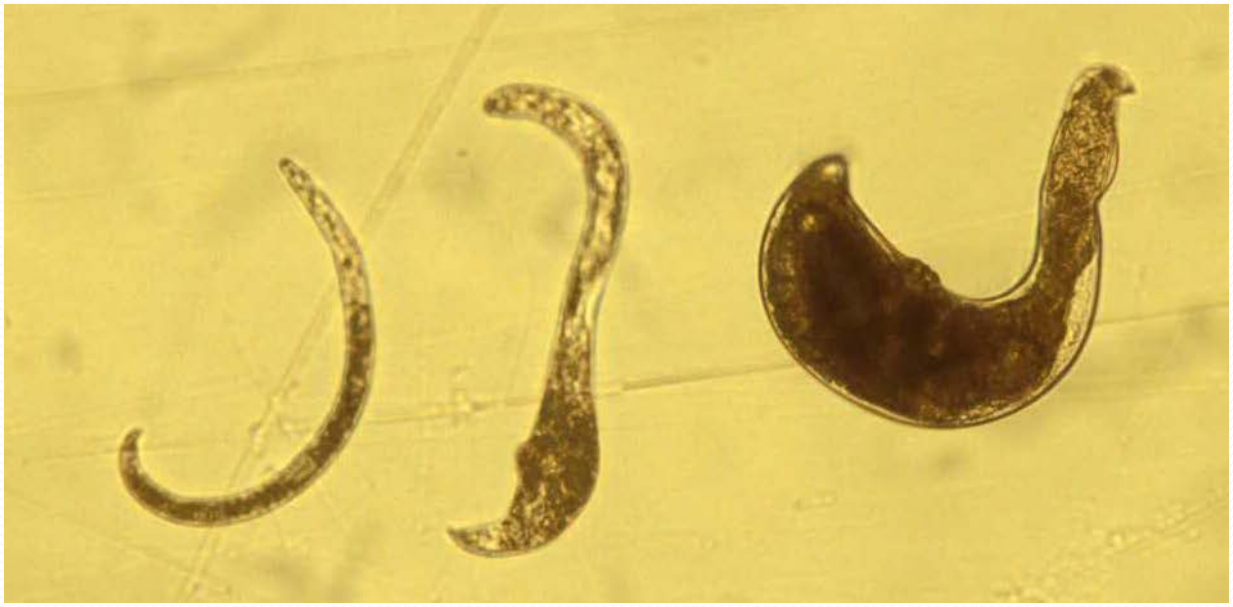
J4

Vermiform stages stay outside of roots

Easy to manage

Crops in Hawaii most damaged by Reniform nematode

Pineapple



Papaya

Cowpea

Sweet potato

Reniform Nematode is a Damaging Pest on Sweet Potato

Healthy sweet potato tubers

Reniform nematode infected sweet potato tubers

The reniform nematode causes root necrosis resulting in severe root pruning, tuber cracking and dwarfing of the plants.

Anhydrobiosis

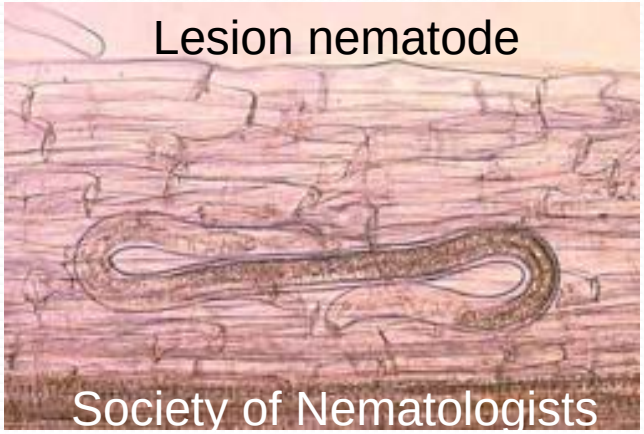
= Some nematodes can survive the loss of all their body water and enter a state of anhydrobiosis in which their metabolism comes reversibly to a standstill.

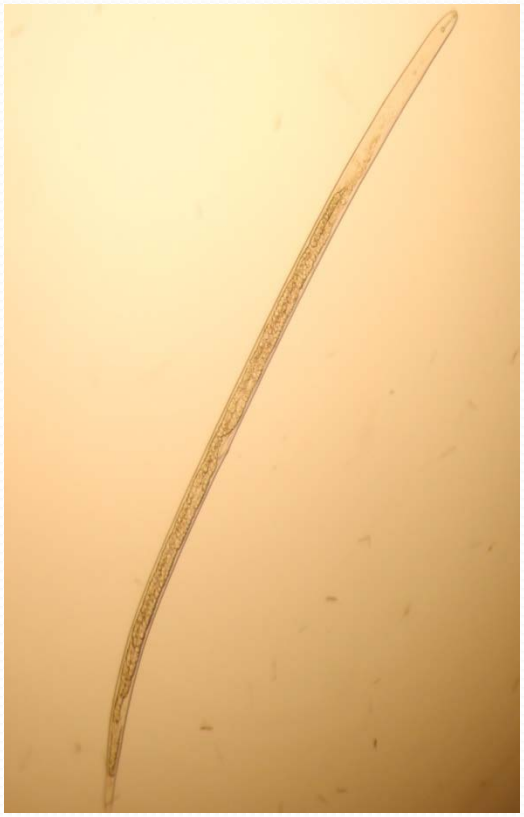
Scanning electron micrography of a nematode after dehydration.
(Sugar Team, http://coursewares.mju.ac.th:81/e-learning47/PP300/0016 sugarteam1014/5605nematode/004%20under%20microscope/page_01.htm)

This is making reniform nematode very difficult to manage.

Migratory Endoparasitic Nematodes

Burrowing Nematode (Radopholus similis)
Lesion nematode (Pratylenchus spp.)

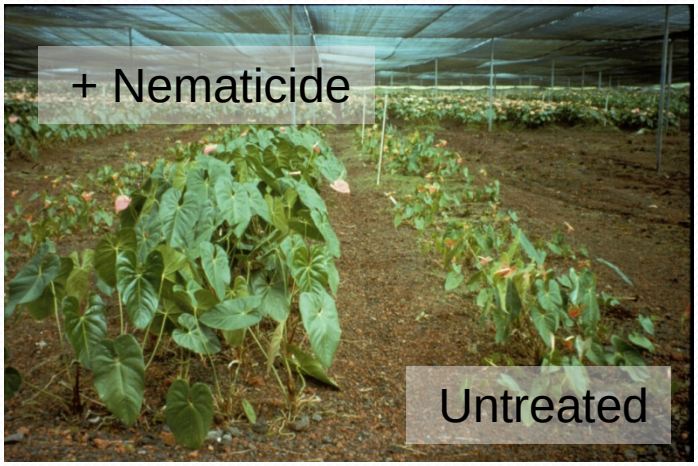




Burrowing nematode

- Both nematodes cause lesions on roots.
- Lesion is most damaging to corn, ginger, and banana.
- Burrowing nematode is most damaging to anthurium, citrus, and banana.

Damages caused by burrowing nematodes



Anthurium decline caused by burrowing nematodes.

Burrowing nematodes can burrow into banana corm tissues, thus carry over to propagative materials.

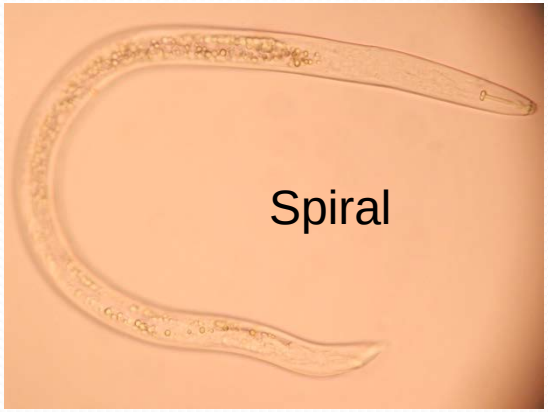
Severely damaged root system resulted in toppling of banana plant.

Cause root lesions on banana roots without functional roots.

Semi-ectoparasitic nematodes

Spiral Nematodes

Some species are damaging to corn, but mostly associated with grassy weeds in agroecosystem.



Helicotylenchus multicinctus

Most wide spread and abundant plant-parasitic nematode found on banana in Hawaii and American Samoa (Wang and Hooks, 2009).

http://www.ctahr.hawaii.edu/oc/freepubs/pdf/PD-69.pdf

Weak root system of banana plant due to nematode infection

Nematodes might have damaged banana roots, but some farmers prop up the plants by wooden sticks and can continue to harvest bananas for years

Foliar Nematode

- Symptoms: lesions that are bounded by the major veins in leaves.
- **Strawberry foliar nematode** (*Aphelenchoides fragariae*) is a disease common in strawberries and ornamental plants including ferns.

- **Chrysanthemum foliar nematode** (*A. ritzemabosi*), parasitizes more than 200 species, most are in the family Compositae.

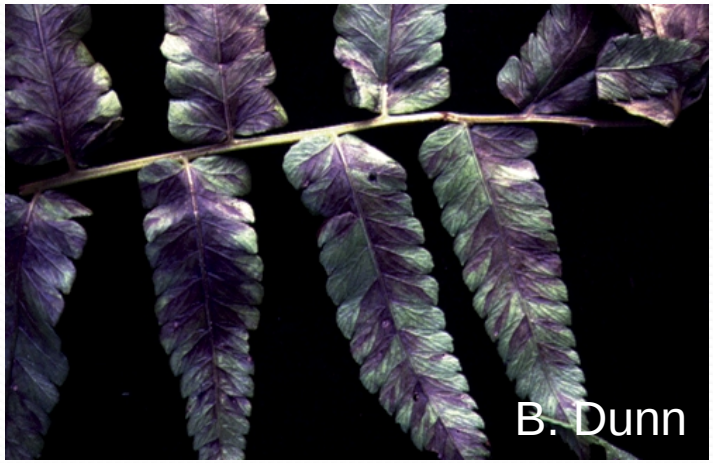
- **Rice white tip nematode** (*A. besseyi*) infects rice and many other grasses, vegetable and ornamentals.

Foliar Nematode (*Aphelenchoides*)

Oncidium

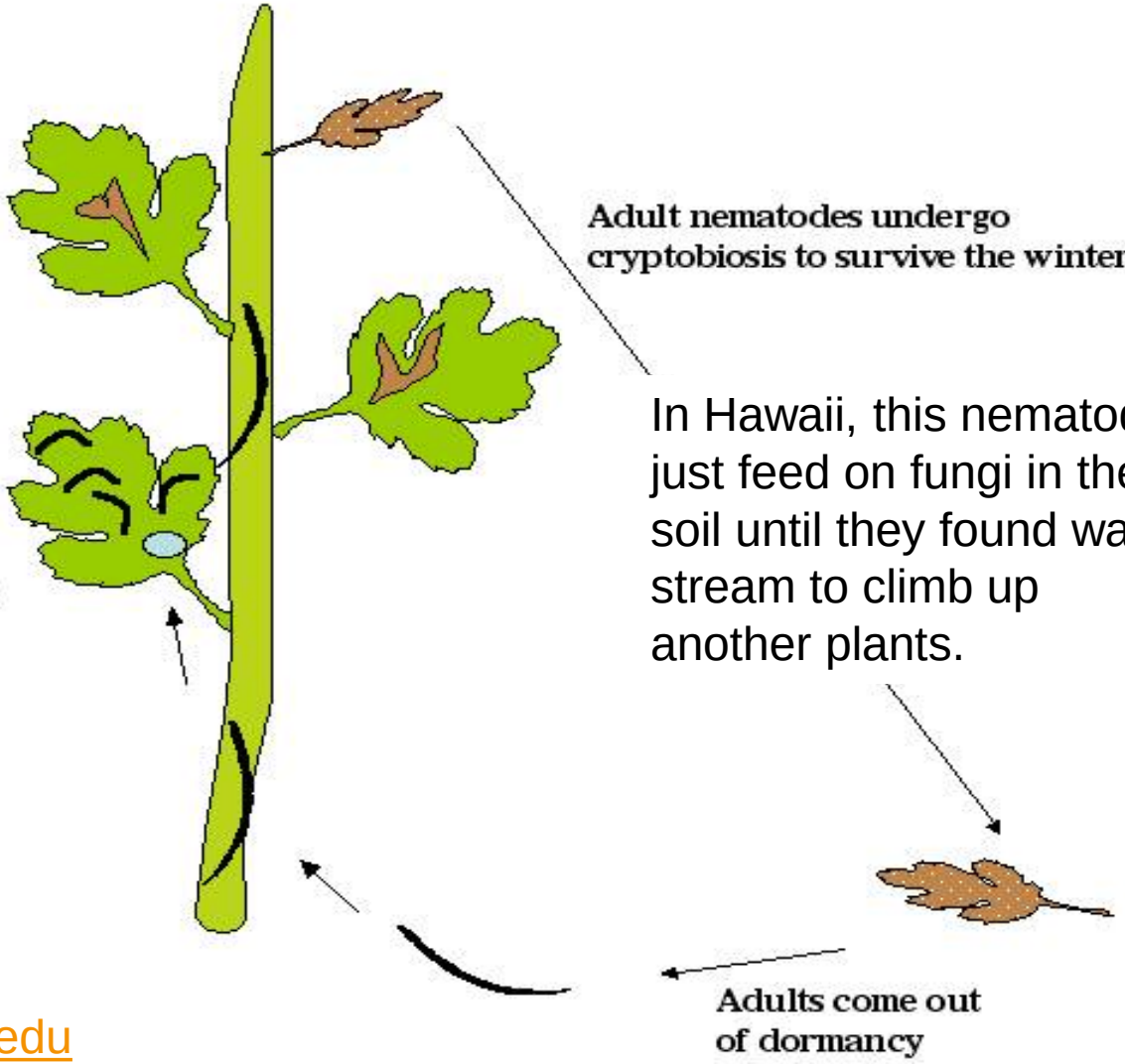
(Uchida and Sipes, 1998)

CTAHR Extension Pub PD-13



Fern

Foliar Nematodes



www.btny.purdue.edu

- The best management practices for this disease are sanitation, and planting clean seed or starter plants. Some insecticides (e.g. neem based) registered for your crop can be used to control foliar nematodes.

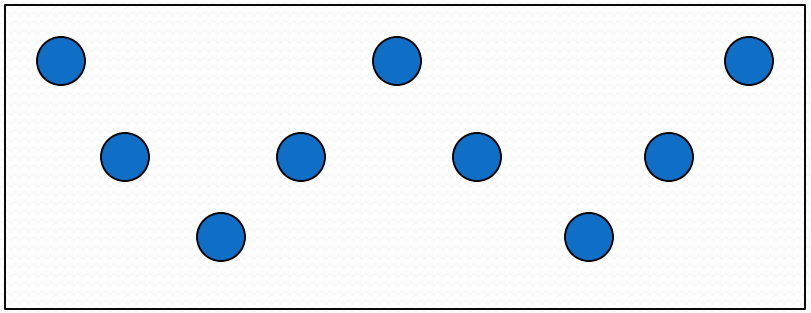
Summary: Key Nematode Pests of Food Crops in Hawaii

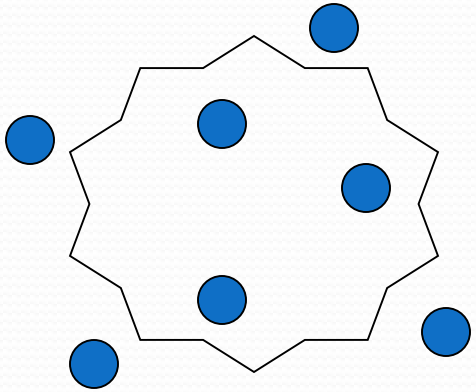
Key Pests	Crops affected
Root-knot nematode (*Meloidogyne* spp.)	Wide host range, okra is among the most intolerant; corn does not show galls but is susceptible.
Reniform nematode (*Rotylenchulus reniformis*)	Wide host range, especially on pineapple, sweetpotato, papaya many ornamental foliage plants; But papaya is tolerant to reniform.
Lesion nematode (*Practylenchus* spp.)	Wide host range, especially on corn, ginger, banana etc.
Burrowing nematode (*Radopholus similis*)	Banana, citrus, anthurium.
Spiral nematode (*Helicotylenchus* spp.)	*H. multicinctus* is damaging to banana, some species are damaging to corn. Most associated with grassy weeds.
Sugarbeet cyst (*Heterodera schachtii*)	Very damaging on cruciferous crops (e.g. cabbage) and *Chenopodiaceae* (sugarbeets, garden beet, and spinach) in Kula, Maui.

Outlines

- Types of plant-parasitic nematodes
- √ How to take soil samples
- √ Nematode Management Options
- Good nematodes

How to take soil sample?





Composite sample

Mix well

Draw 1 pint

Send to soil processing lab
e.g. Agriculture and Disease Diagnostic Lab, UH
http://www.ctahr.hawaii.edu/site/ADSC.aspx

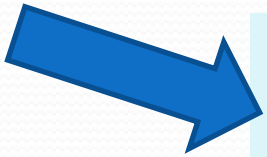
Nematode Management Options

- Chemical
- Cultural
- Physical
- Biological

- Preplant fumigation (1,3-dichloropropene):
  - Too costly for small-scale farmers, potentially contaminate ground water.
- Post-plant nematicide:
  - Nemacur (fenamiphos): Special Local Needs label for Hawaii had expired on June 04, 2007.
  - Mocap (ethoprop): post-plant application.
  - DiTera: Biopesticide, hard to handle.

Nematode Management Options

- Chemical
- Cultural
- Physical
- Biological

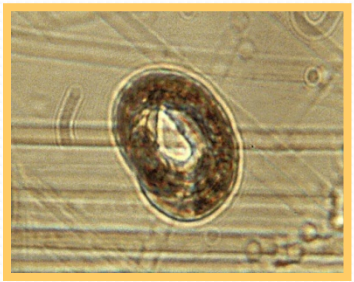


- Fallow
- Using nematode-free planting materials
- Crop rotation with Cover crops
- Resistant varieties
- Grafting to resistant root-stock
- Induce systemic resistance

Fallow

Pineapple

- Pineapple plantation generally fallow their field for 12 months before next planting.
- Without the present of plant host, **reniform nematodes** could turn into anhydrobiotic stage to survive.



Banana

Martinique……..

*Fallow/tissue culture plant regime has extended banana field longevity from 3-4 to 6-10 years, in some cases contaminated fields are totally freed from **burrowing nematodes**.*

Using nematode-free planting materials

Banana

- Hot water treatment (commercial practice in Australia and Central and South America)
- Na-hypochlorite dip
- Tissue culture plantlets ($2.50/plant from ADSC)
- Root paring

Hot water treatment (55°C for 10-20 minutes depend on plant size)

Peeled banana corms
http://plpnemweb.ucdavis.edu/nemaplex

Root paring

Cover Crops with Allelopathic Compounds against PPN

Sunn hemp
Crotalaria juncea
-- monocrotarine

T. erecta and *T. polynema* are resistant to root-knot but very susceptible to reniform nematodes.

French Marigold
Tagetes patula
-- α-terthinyl

Rapeseed (Canola)
-- glucosinolate

Sorghum-sudangrass
-- Dhurrin

Use Marigold as Living Mulch

- The toxic compound in marigold (α-terthienyl) is only toxic to nematodes through photoactivated, meaning it must be growing to release the toxic.

Plant marigold here for 2-3 months before planting cash crop.

Plant marigold about 5 months after banana keiki established to avoid competition.

The secret of Sunn Hemp in Suppressing Plant-parasitic Nematodes

Mechanisms:

1. Serves as a poor host
2. Produce allelopathic compound against plant-parasitic nematodes when incorporated into soil
3. Produce organic matter, can enhance nematode-trapping fungi
4. Enhance beneficial nematodes and soil arthropods involved in soil nutrient cycling, thus increase plant tolerance

Sunn hemp superhero video:
http://www.youtube.com/watch?v=AG_CYsVmqN4

Effect of crop age, tissues, and biomass amount on SH allelopathic effects



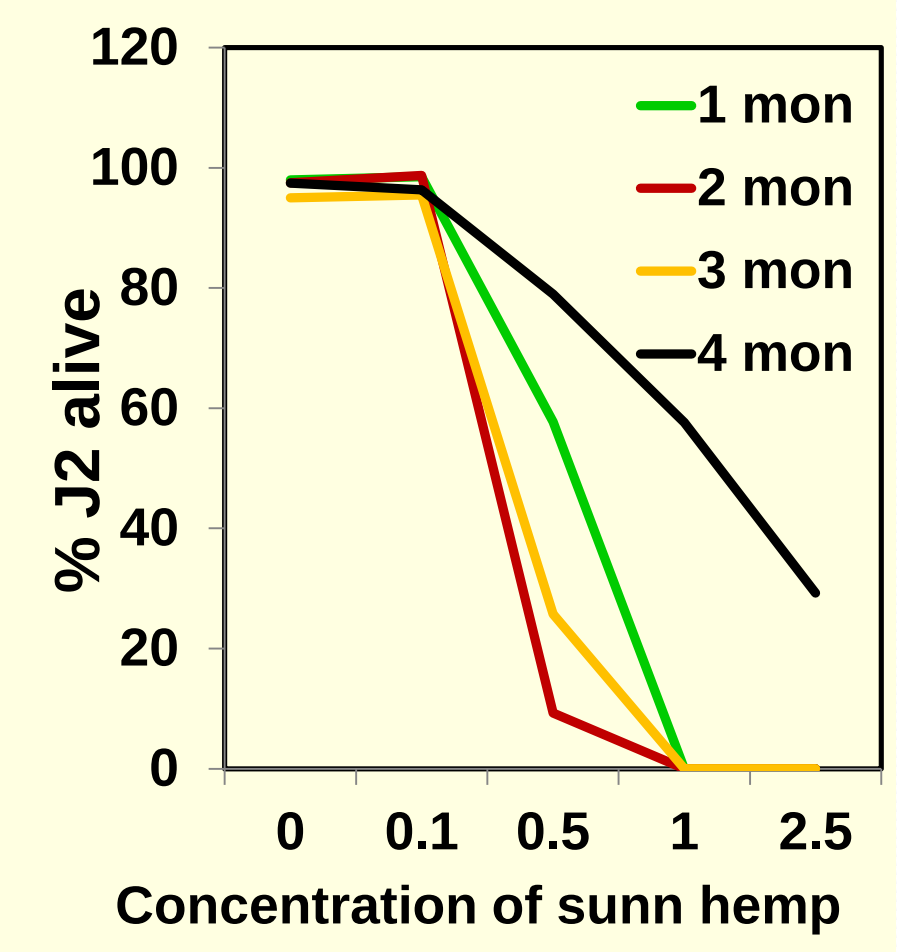

1 month | 2 month | 3 month | 4 month

4 ages ×	4 tissues ×	5 Concentration
	Leaf	2.5%
	Stem	1.0%
	Flower	0.5%
	Roots	0.1%
	Whole plant	0

4 dishes
2 trials

Effect of crop age, tissues, and biomass amount on SH allelopathic effects

- SH Leaf tissue was most suppressive, and the result resembled those in the whole plant tissues.
- The suppressive effect is just nematostatic.
- Leachate had minimum effect on egg hatching.
- Suppressive effect of SH is most significant at 3-month old.
- Suppressive effect decreased at 4-month old.

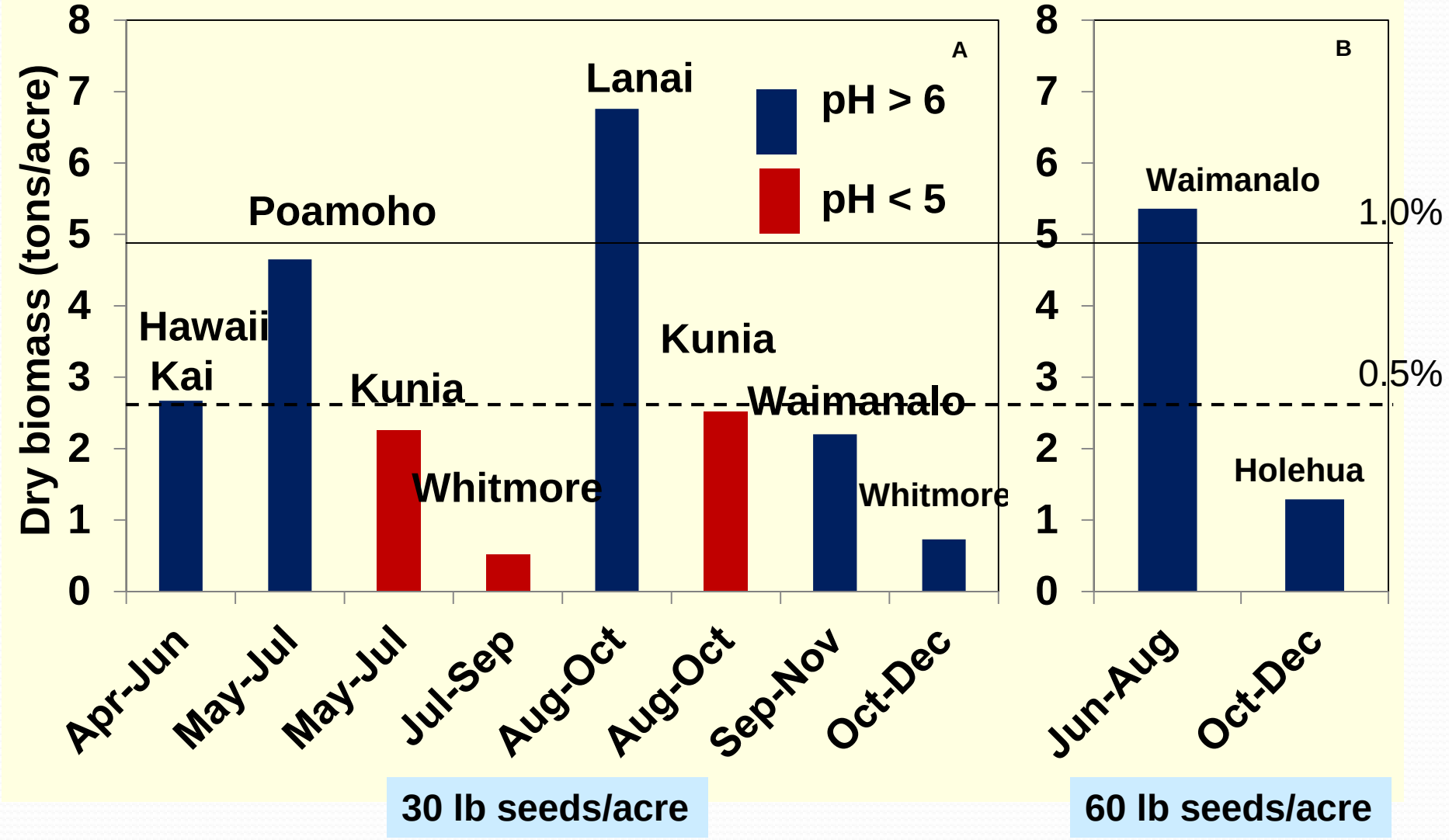


Can we generate this amount of sunn hemp biomass in the field?

Conc (%)	Dry Biomass (tons/acre)
0.1	0.5
0.5	2.5
1	5
2.5	12.5

Yes, easily!

Biomass of 2-3 month-old Sunn Hemp commonly seen in Hawaii



Nematode Management Options

- Chemical
- Cultural
- Physical
- Biological

- Solarization

- Usually soil solarization cover the soil with clear plastic (1 mil) for 4-6 weeks to be effective.

- Raise soil temperature (35-60ºC) pending on heat exposure.
- Suppress plant-parasitic nematodes, other soil pathogens, weeds and arthropods.

Exposure Time to kill Root-knot nematodes

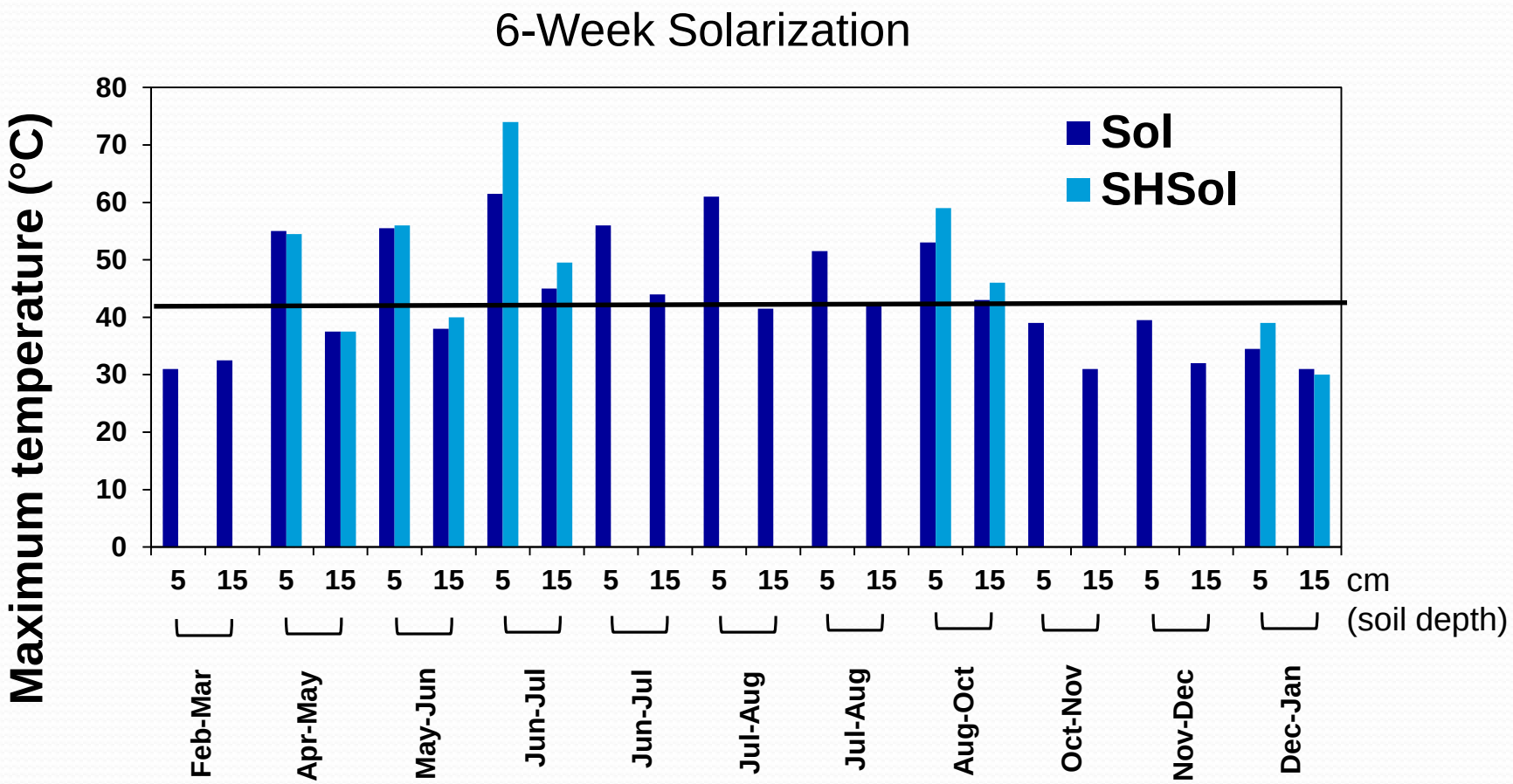
Temperature (°C)	Hours to kill 100%		Heat units to kill 100%	
	Eggs (Hours)	J2	Eggs (Degree hours)	J2
38	389.8	-	14812	-
39	164.5	47.9	6415	1868
40	32.9	46.2	1316	1848
41	19.7	17.5	808	718
42	13.1	13.8	550	580

Heat units = $(T_m - 38°C) \times$ hours of exposure

Kill of root-knot at sublethal temperature is not determined by heat units. By accumulating up to 14 hours at 42°C can kill 100% of root-knot nematodes.

(Wang and McSorley, 2008)

Solarization Temperature Scheme in Hawaii

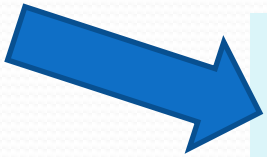


Solarization between April to Oct is effective.

(Wang 2011)

Nematode Management Options

- Chemical
- Cultural
- Physical
- Biological



- Fallow
- Using nematode-free planting materials
- Crop rotation with Cover crops
- √ Resistant varieties
- √ Grafting to resistant root-stock
- √ Induce systemic resistance

Resistant Crops or Varieties

(for root-knot nematode management)

Crop rotation

strawberry

oat

Sweet pepper is resistant to Javanese root-knot (*M. javanica*) but not Southern root-knot nematode (*M. incognita*).

- Northern root-knot (*M. hapla*) is damaging to strawberry but is not common in Hawaii.
- Oat is a non-host.
- However, these crops do not kill the root-knot population infested in the soil.

Resistant varieties (ADSC)

N-5, N-63, N-65, Komohana

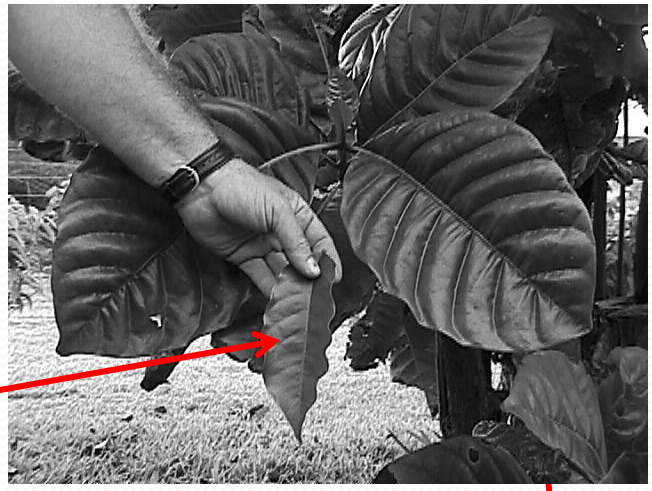
Healani, Kewalo

Poamoho Pole Bean

Grafting

- Coffee farmers in Hawaii graft commercial coffee variety, Kona typica (*Coffea arabica* 'Guatamala') to root-knot nematode resistant root stock, Fukunaga (Bittenbender et al., 2001).
- http://www.ctahr.hawaii.edu/oc/freepubs/pdf/NPH-6.pdf

Grafting clips used for securing the graft



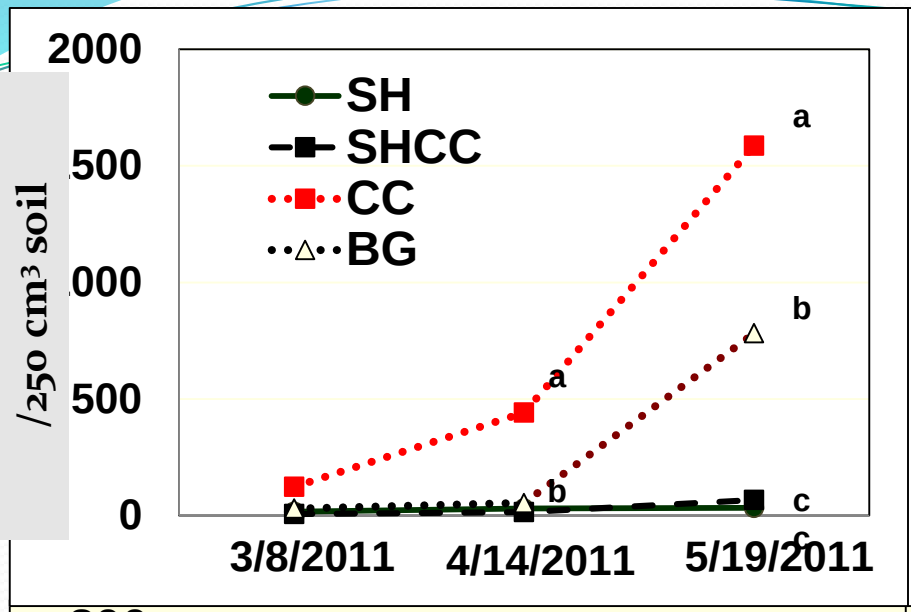
Induce Systemic Resistance

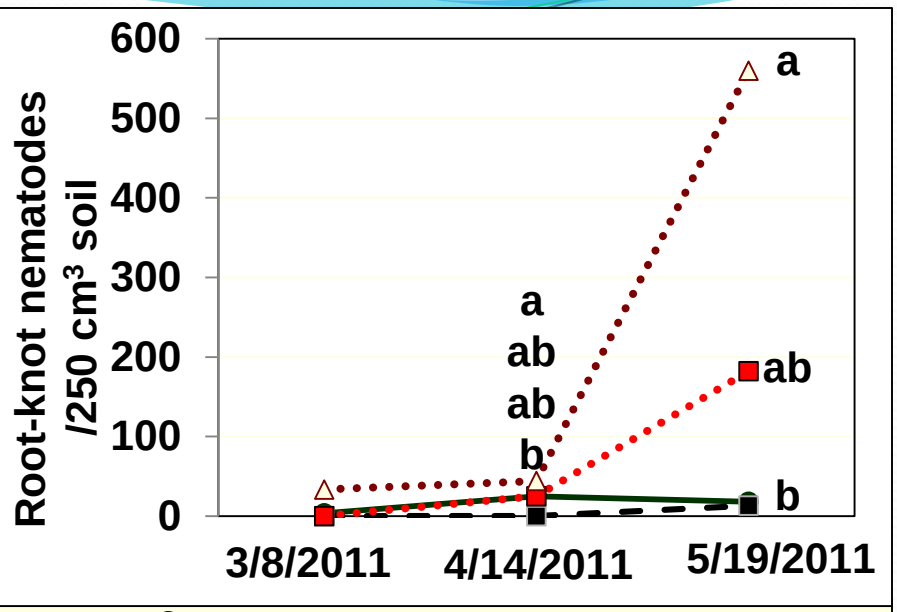
- Through drenching of chicken manure based vermicompost tea.

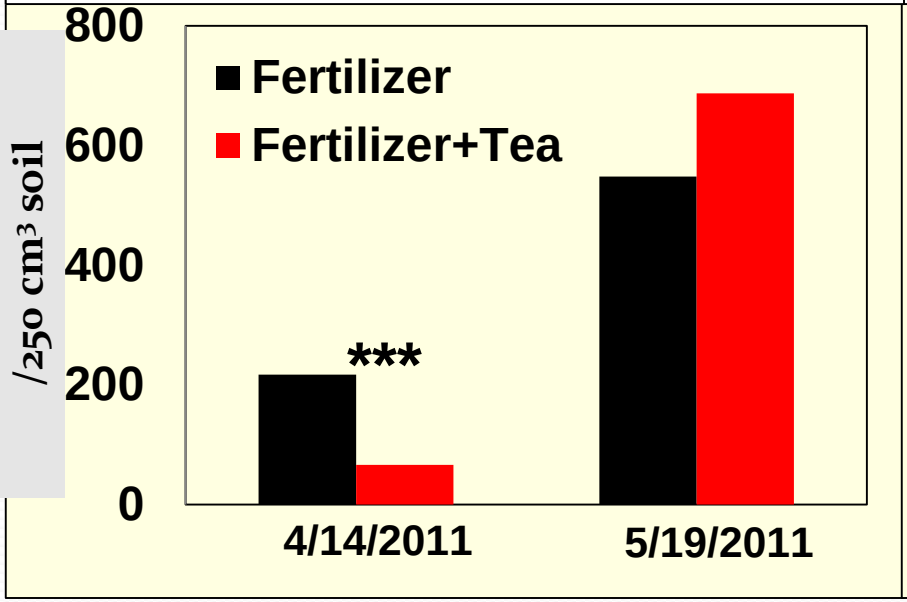
Vermicompost tea (VCT)

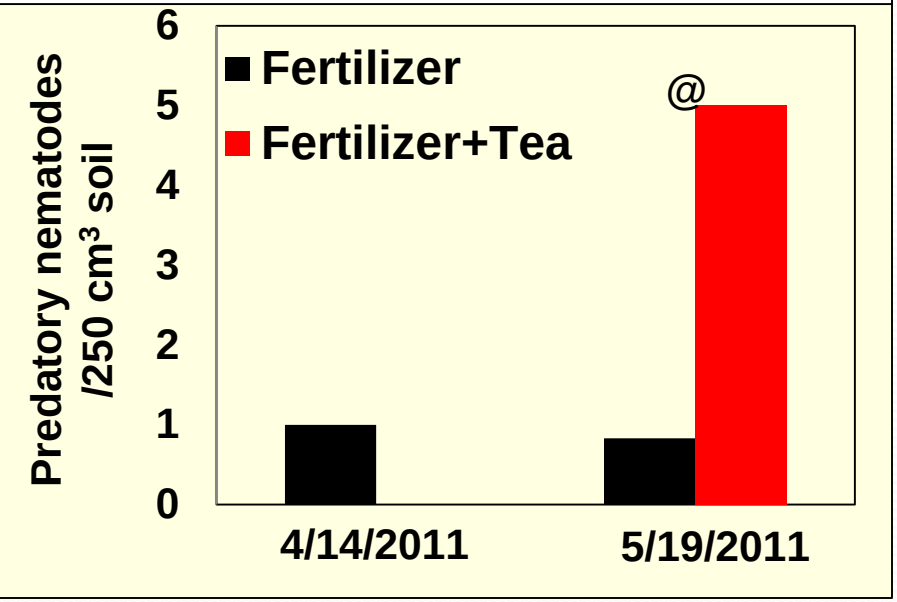
Sunn hemp and chicken manure are known to be suppressive to PPN.

Effects of cover crops and VCT on reniform nematodes



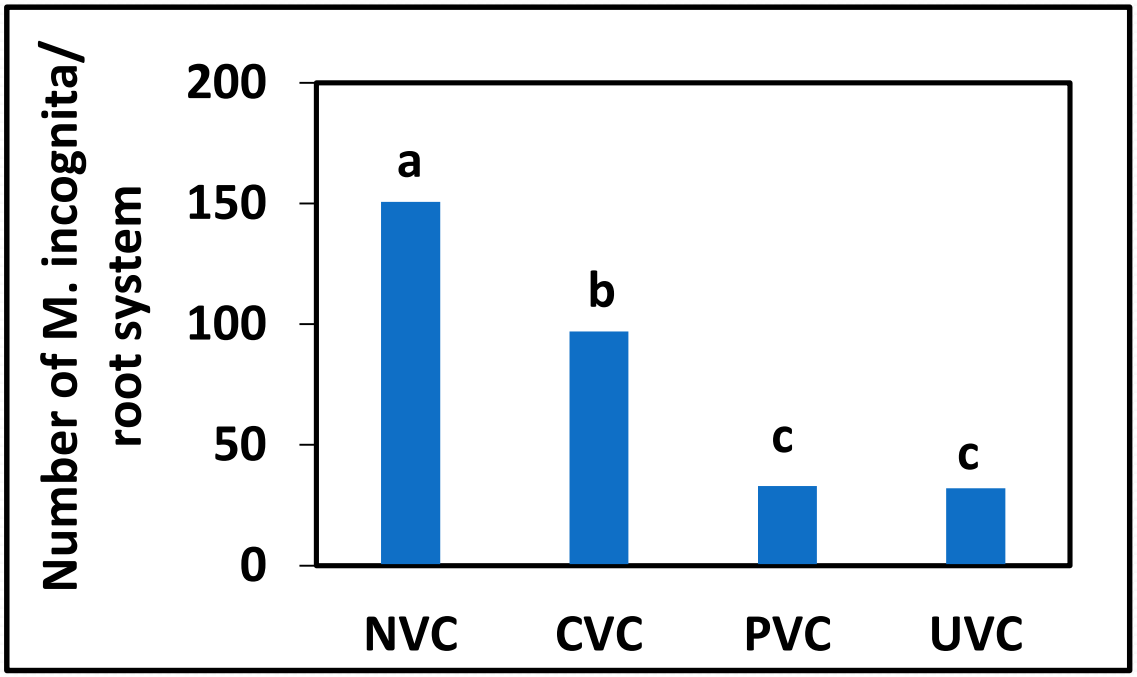






@ = significant difference between Fertilizer and Fertilizer + CT

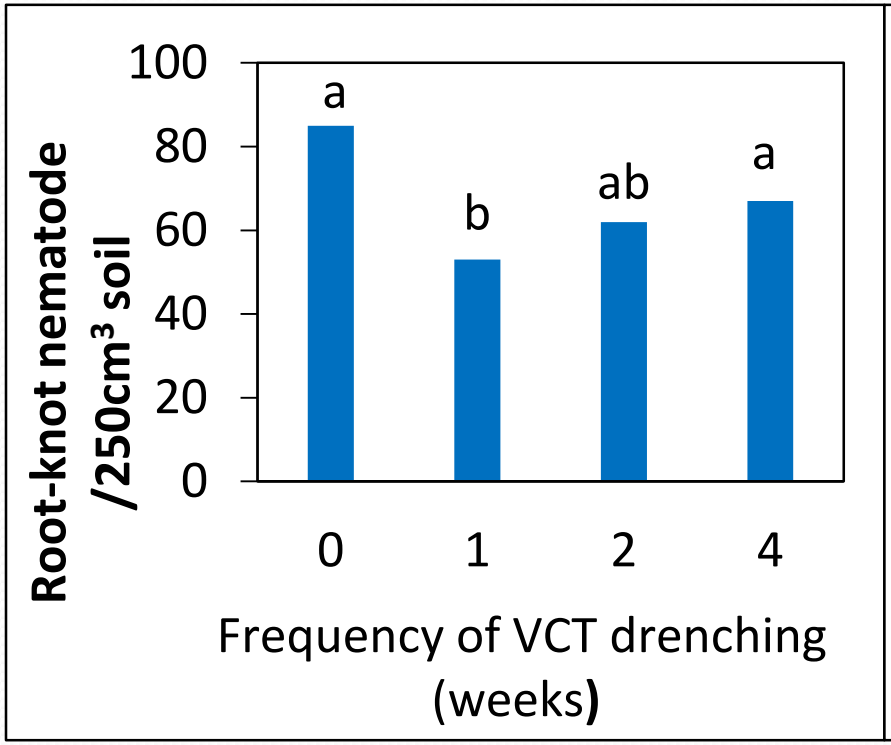
Effects of VC'S Curing Age on Root Penetration of Root-knot (*M. javanica)*

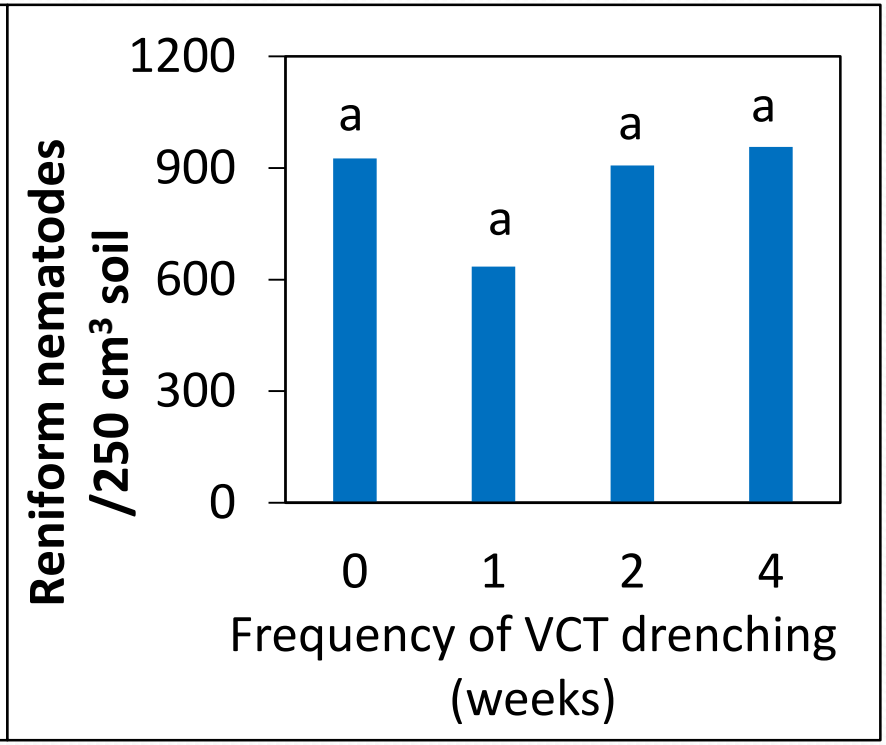


- UVC and PVC consistently suppressed RKN penetration, but CVC occasionally suppressed RKN penetration.

NVC: Water
CVC: completely cured VC(> 2 months)
PVC: partially cured VC (1-1.5 months)
UVC: uncured VC (< 1 week)

Field trials: Effects of VCT Drenching Frequency on Plant-parasitic Nematodes

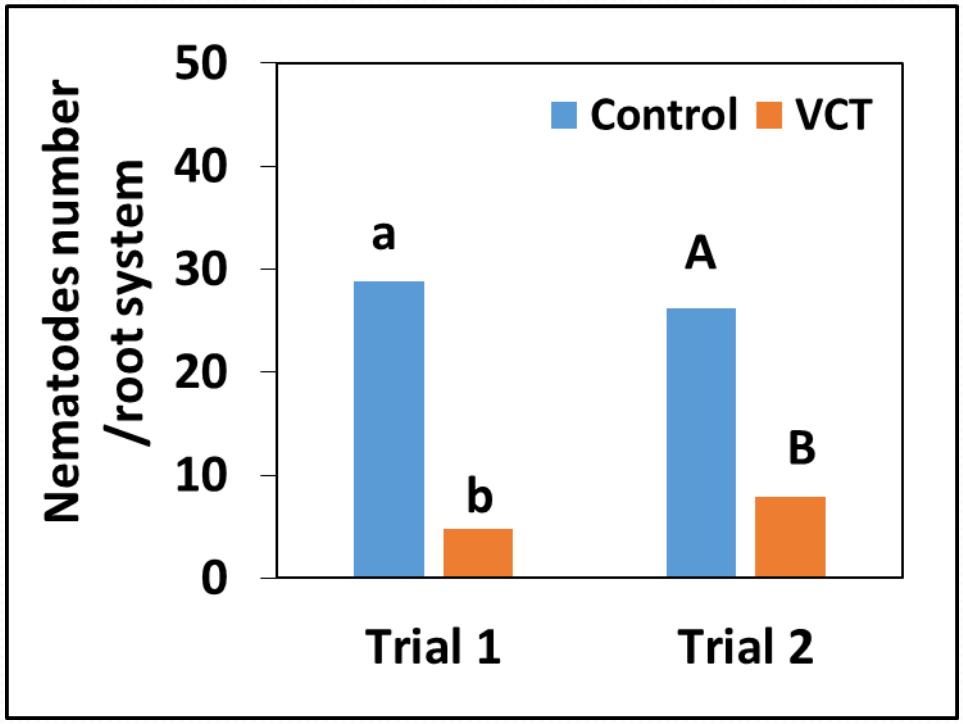




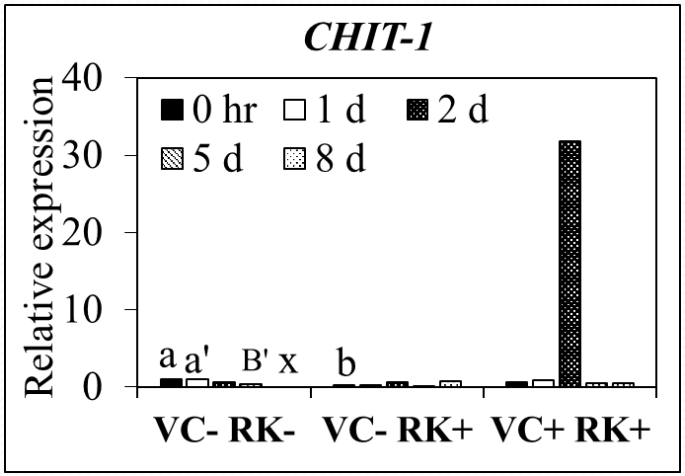
1-wk VCT drenching suppressed RKN but not reniform nematodes.

VCT induced host plant resistance against RKNs

Split-root Experiment



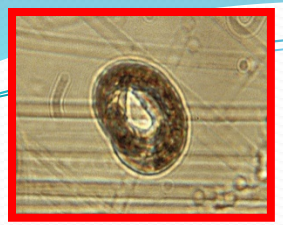
Gene expression experiment suggested that VCT from UVC could induce ISR through the expression of *CHIT-1, PAL-1* and *LOX-1* in VCT drenched plants, but not *PR1*, and *β-1,3-Glucanase. But the ISR effect is transient.*



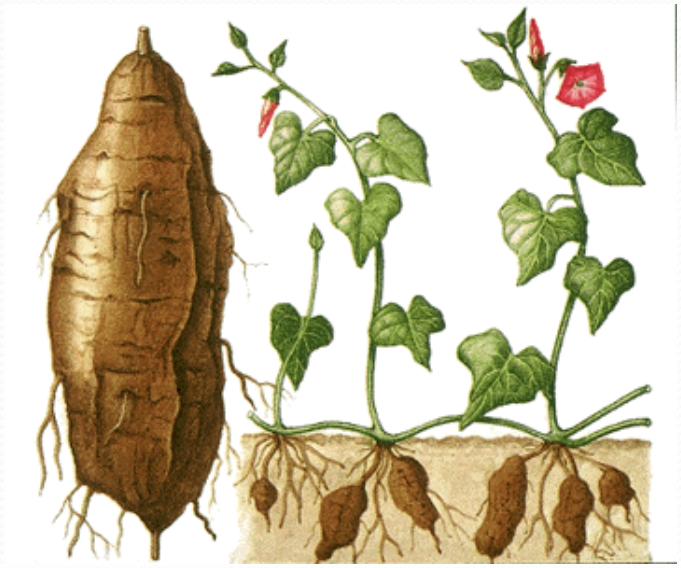
Nematode Management Options

- Chemical
- Cultural
- Physical
- √ Biological

√
- Target on the venerable stage of the nematodes
- Natural enemies of plant-parasitic nematodes
- Enhance beneficial nematodes
- Biopesticides



Anhydrobiotic reniform nematodes are hardy, can survive drought condition, and revive after a susceptible host is planted

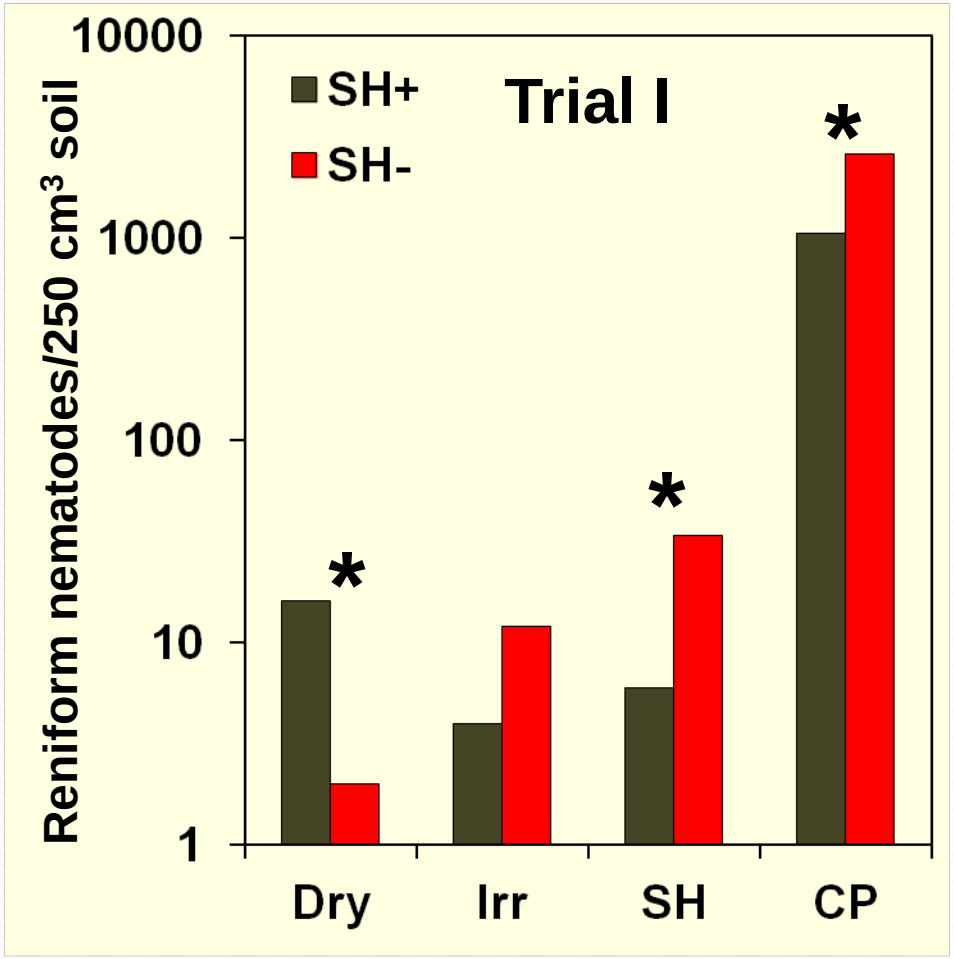


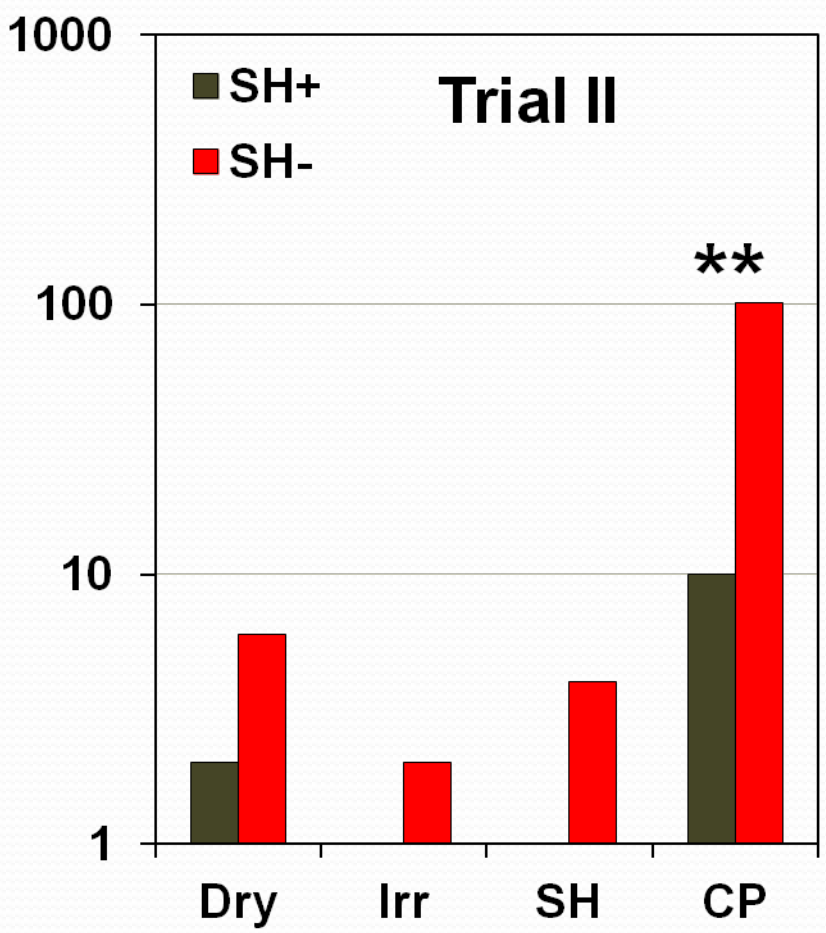
Vermiform stage

- Vermiform stage nematodes are known to be easier to kill than the survival stage.
- Can we stimulate reniform to turn into vermiform stage so that SH can kill reniform more efficiently?
- Student discussion

SH suppressed reniform if previously planted with poor or good host

Reniform infested soil amended (SH+) or not amended (SH-) with SH at 1% (w/w)





*** = significant difference between SH+ and SH-**

(Marahatta, Wang et al., 2012 Nematropica 42: 34-40)

Implication for Sweet Potato farmers

Fallow could knock down the population number of reniform and kill off infected sweet potato.

Plant sunn hemp during spring or summer for 2 months (in soil pH > 5) with irrigation, till in sunn hemp biomass (preferred 5 tons/acre) before planting sweet potato.

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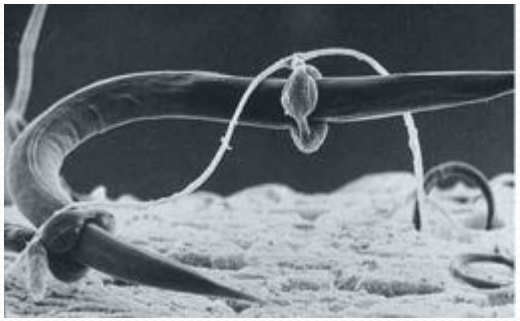
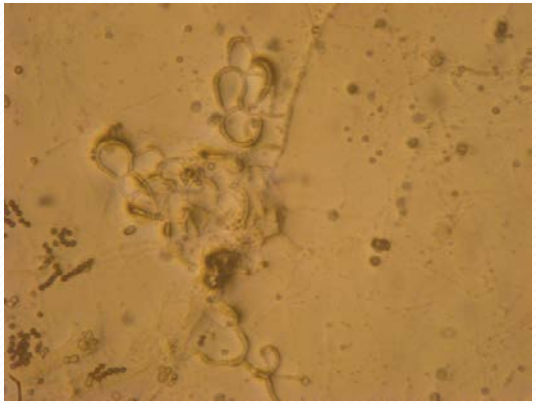
Natural Enemies of Plant-parasitic Nematodes: Nematode-trapping fungi



Nematode-trapping fungi
-- form constricting rings

Dactylaria ellipsospora
-form adhesive knobs

-form adhesive 2°nets



A. oligospora
-form adhesive 3°nets

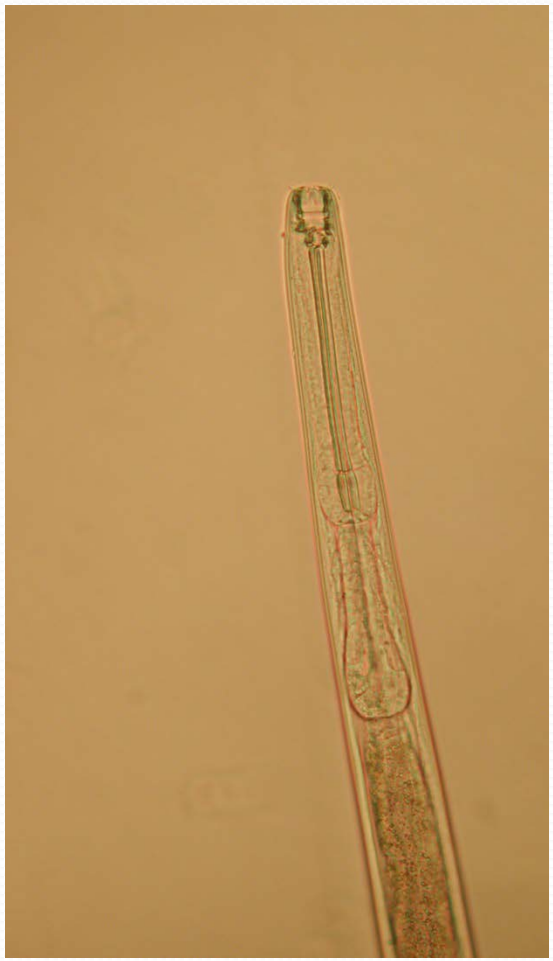
Arthrobotrys dactyloides

Natural Enemies of Plant-parasitic Nematodes: Bacteria

Pasteuria penetrans **infecting a burrowing nematode.**

Pasteuria penetrans **infecting a root-knot nematode**

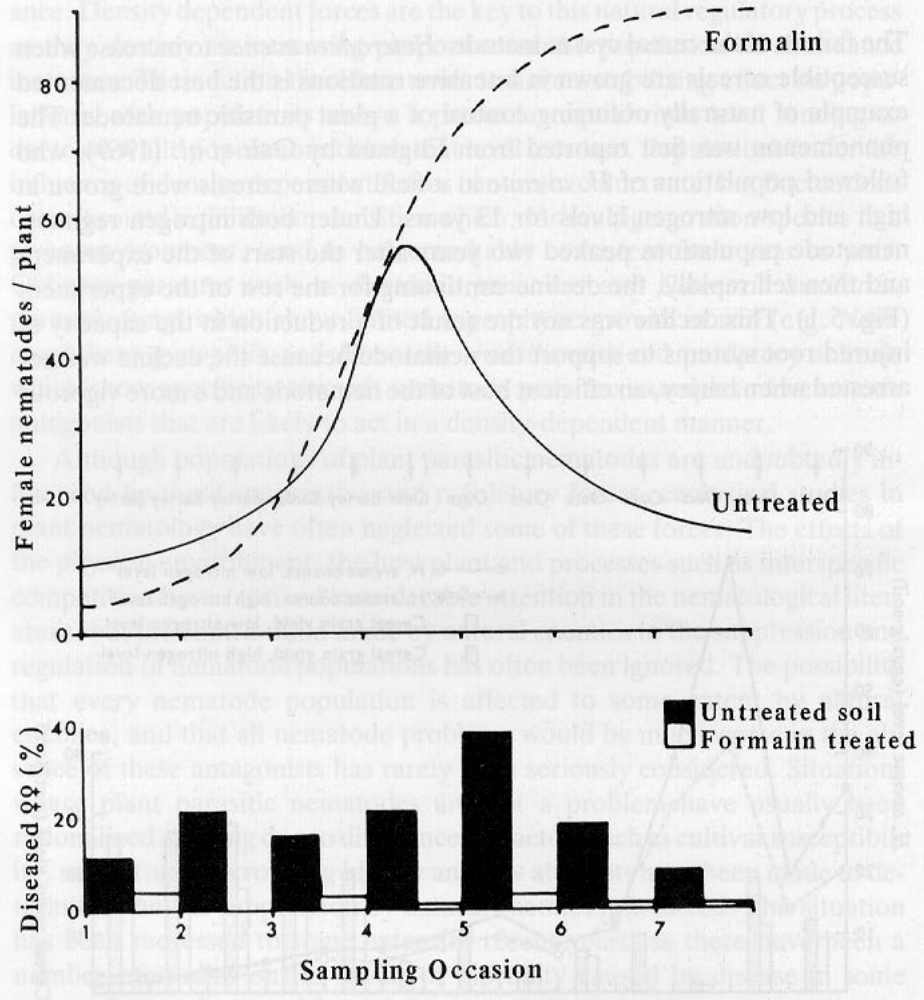
Predatory nematodes



Butlerius

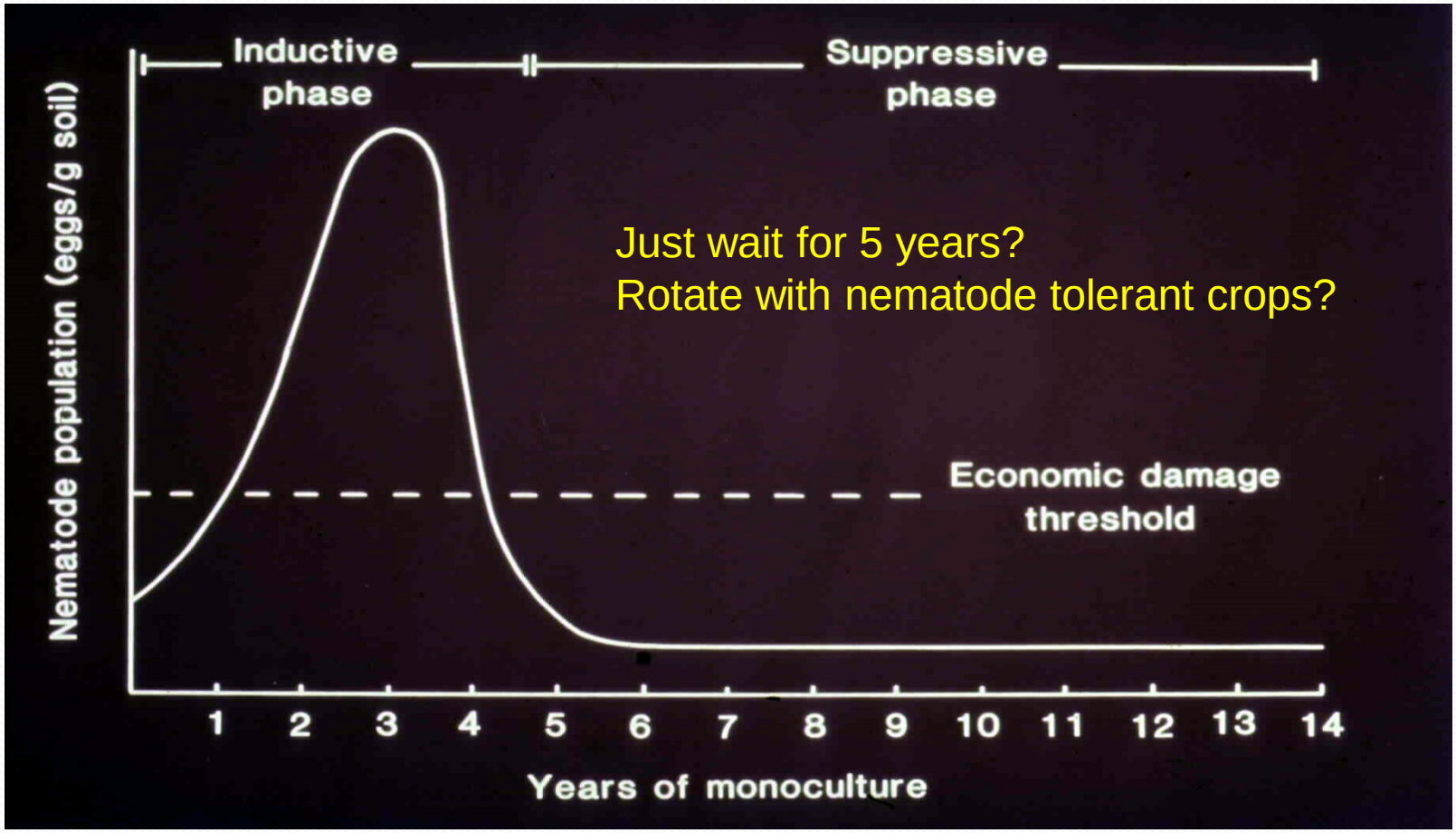
Decline of Cereal Cyst Nematode (CCN)

- Decline of CCN in cereals monoculture in UK (Gair et al., 1969).
- Application of formalin increased the multiplication of CCN.
- *Nematophthora gynophila,* Pochonia *chlamydosporium, Catenaria auxiliaris,* were widespread (Kerry, 1975)



Suppressive Soil

- Naturally equilibrated systems i.e. suppressive soils
- Most of these fungi do occur in natural populations



Nematode Management Options

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Using nematodes as soil health indicators

Bacterivore **Fungivore** **Herbivore** **Omnivore** **Predator**

EI=Enrichment index

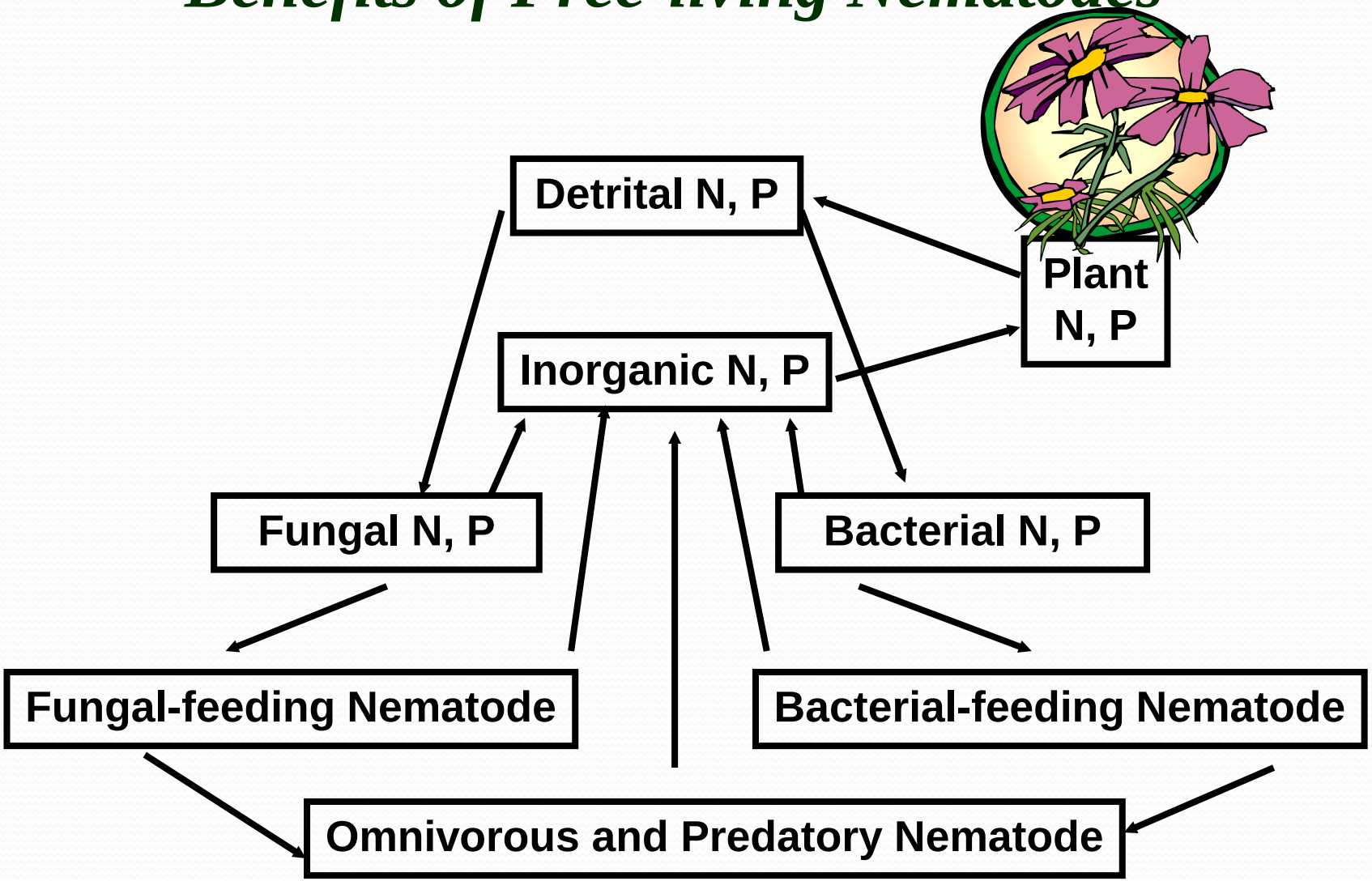
CI=Channel index

SI=Structure index

+ richness, diversity

(Ferris et al, 2001; Neher, 2001)

Benefits of Free-living Nematodes



(modified from Ingham *et al*., 1985)

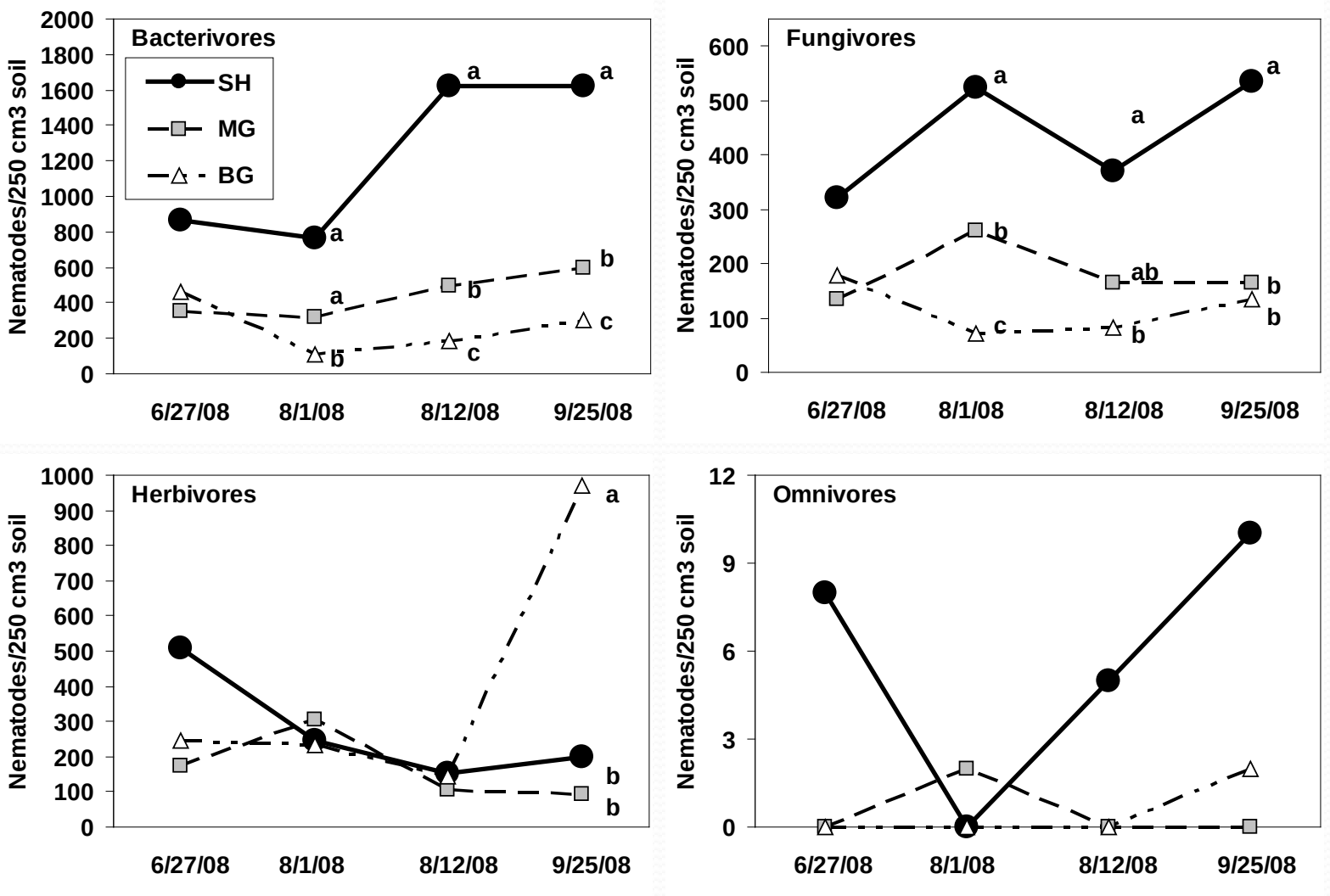
Strip-Till Cover Cropping (STCC)

- Preplant Treatment:
  - ❑ Sunn hemp (SH): 40 lb seeds/acre
  - ❑ Marigold (MG): 2.6 lb seeds/acre
  - ❑ Bare ground (BG): fallow with weeds

2008, 2009 Trials

- Advantage:
  - STCC reduced tillage.
  - Periodical clipping of the living mulch as surface mulch provide additional inputs of organic matter over time.

SH enhanced free-living nematodes (improve soil health), suppressed plant-parasitic nematodes



(Wang et al., 2012: Applied Soil Ecology 49: 107-117)

Nematode Management Options

- Chemical
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- Target on the venerable stage of the nematodes
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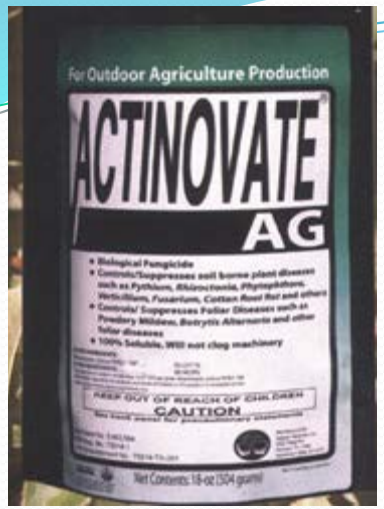
- Enhance beneficial nematodes
- √ Biopesticides
  - Actinovate
  - Shrimp shell meal



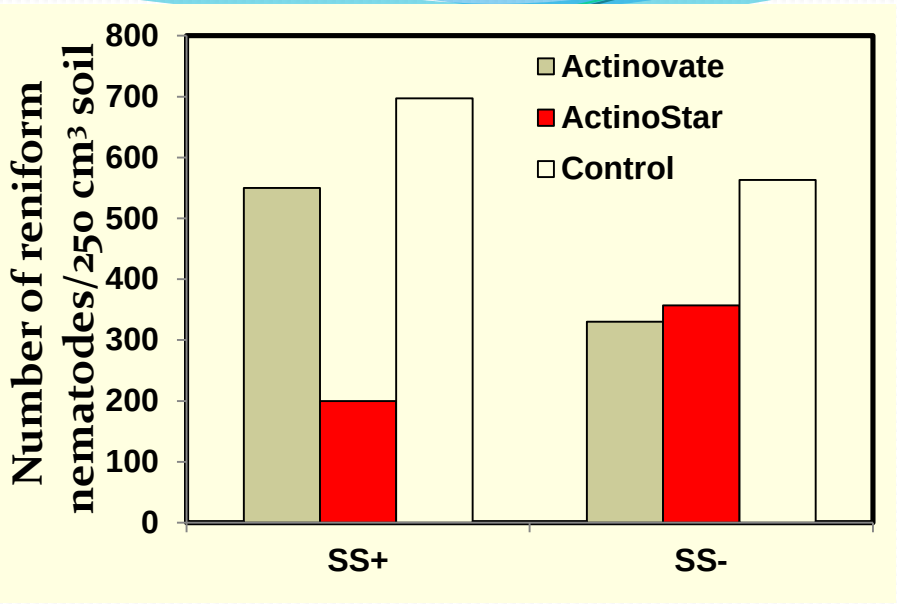
- **Actinovate AG** is a high concentration of a patented beneficial organisms on a 100% water soluble powder.
- a.i. = Streptomyces lydicus strain WYEC 108
- An effective preventative spray for many soil-borne and foliar fungal diseases.
- Effect on nematode suppression is not convincing.

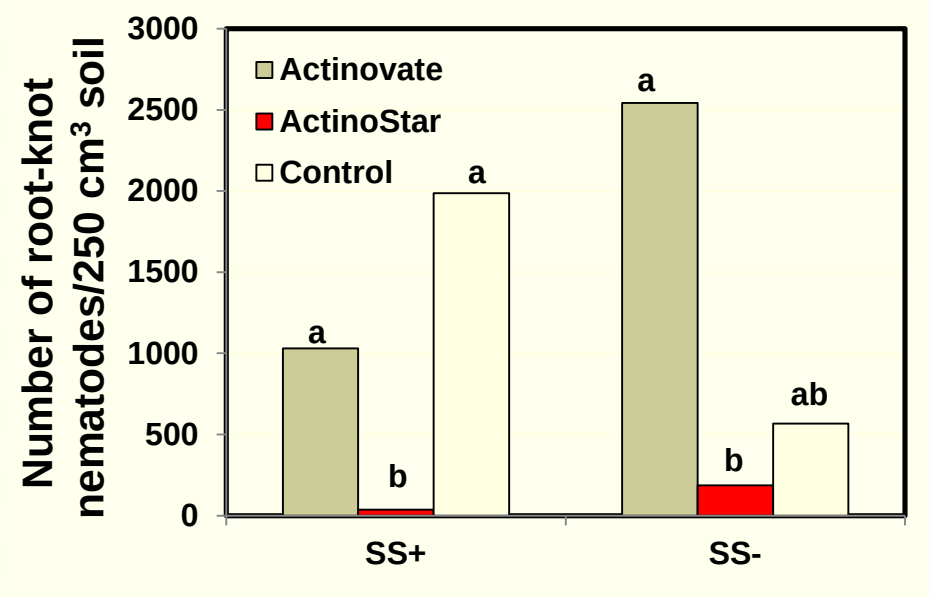
- Shrimp shell meal is a slow-release organic fertilizer (5% N, 8% P, 15% Ca & 18% chitin & trace minerals), derived from ground-up shrimp shells.
- Used in Asia for its nematicidal properties.
- Enhance beneficial soil chitin-feeding microbes.
- Nematode egg shell is composed of chitin.

ActinoStar / Shrimp shell meal

- Shrimp shell meal (SS) +/- (35 lb/1000 sq ft)

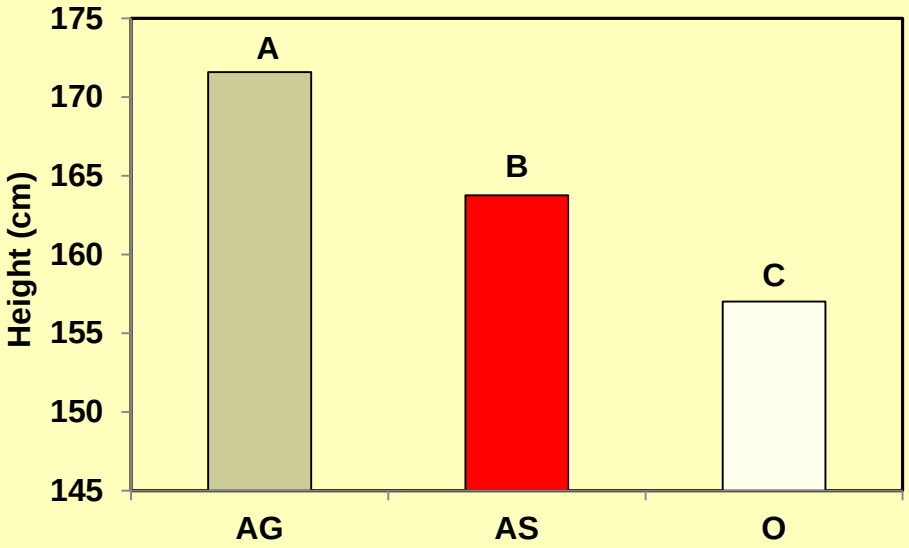
- Actino-Star (AS) 6 oz/acre
- Actinovate (AG) 6 oz/acre
- Untreated control (C)

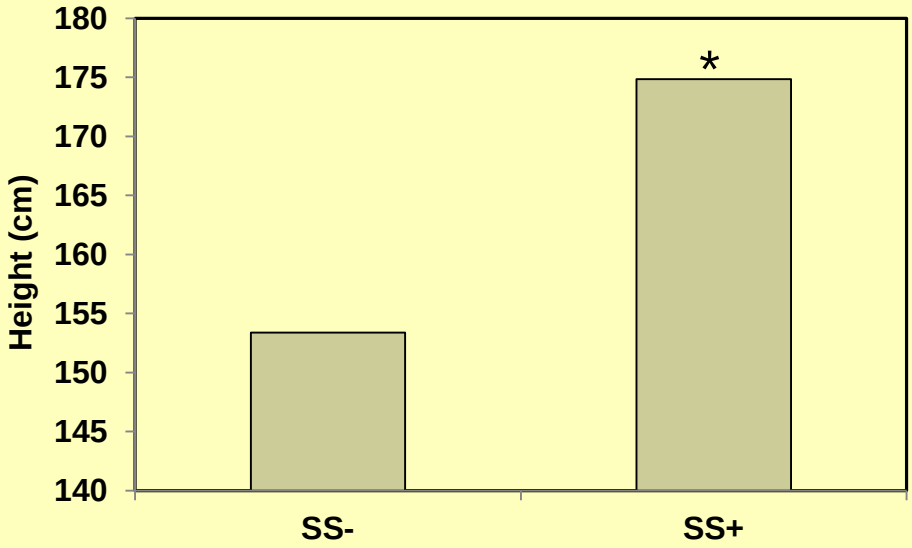




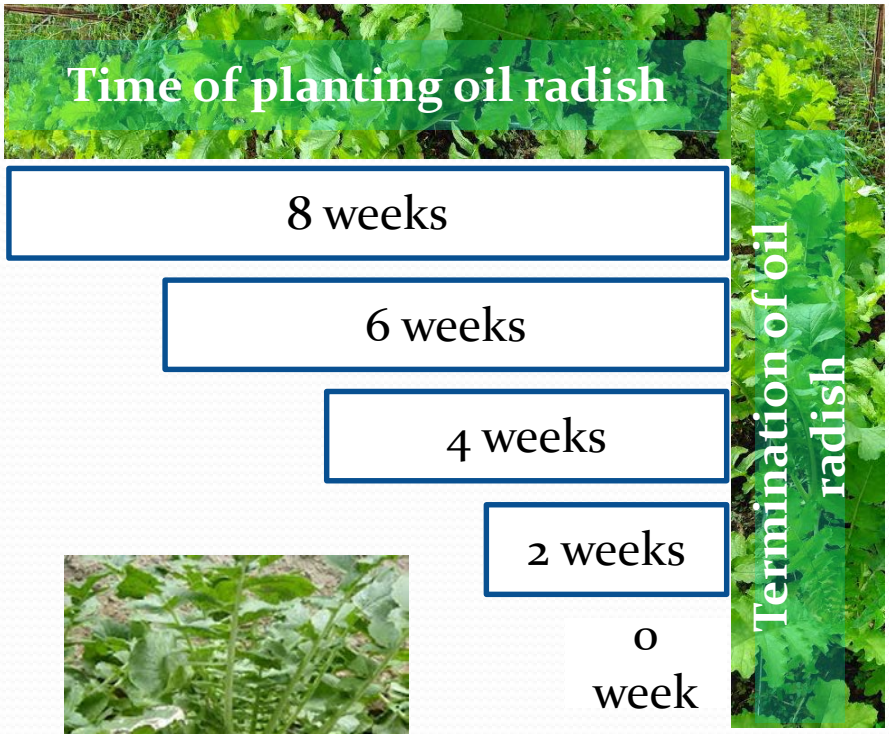
ActinoStar / Shrimp shell meal

ActinoStar /Shrimp Shell Meal





On-going Research: Trap and Fume



Oil radish (*Raphanus sativus*)

Questions:

- How long do we allow OR to trap before RKNs reproduction occur?
- How to maximize biofumigation effect of OR residues?

Field Sanitation for Pest Control

- Remove cull fruits
  - Fruit flies, pickle worm
- Plow up crop residues
  - Nematode infected roots
- Rogue out virus infected plants

Pickleworms on cucumbers

Kill BBTV infected plants with glyphosate

Root-knot nematodes on bitter melon roots

Field Sanitation for Pest Control

- Remove early symptomatic diseased tissues
- Destroy heavily infected crop

- Start with clean seeds (certified seeds)

Basil Downy Mildew
Peronospora belbahrii

Discard infected seedlings

Field Sanitation for Pest Control

- Remove alternative host
  - Portulaca is host of thrips that carry IYLV

Remove and destroy portulaca weeds

Irish Yellow Lethal Virus transmitted by onion thrips

Field Sanitation for Pest Control

- Soil fumigation for soil-borne diseases

Solarization after rapeseed incorporation

Fusarium wilt of lettuce

IPM and Cover Crop Calculator Field Day

June 27, 2015 (Saturday) 9:00 am
Poamoho Experiment Station