Integrated nematode management Options for Florida

In Service Training February 22, 2023

New Technology for Commercial Crop production

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Training Objectives and Goals:

Learn the importance of specific plant-parasitic nematode problems in Florida

Understand the fundamental importance of integrated nematode management

Learn about management strategies to reduce specific nematode impacts as well as their limitations

57 billion nematodes for every human

Nematodes (roundworms) are very effective parasites

Nematodes have been identified as amongst the most serious threats to global agriculture

Big giveaway

Plant parasitic nematodes are part of what has been called the 'big giveaway' with regards to global food insecurity (Sikora *et al.*, 2020).

Farmers around the world feed unwillingly a large proportion of the food they produce to insects, nematodes and diseases without any compensation (Savery *et al.*, 2019) ('free-loaders')

Plant parasitic nematodes have been calculated to reduce up to 10% of the world's agricultural output, causing economic losses valued at over US$125 billion each year (Chitwood, 2003).

Our inability to adequately control many nematodes makes them a significant part of the 'big giveaway'.

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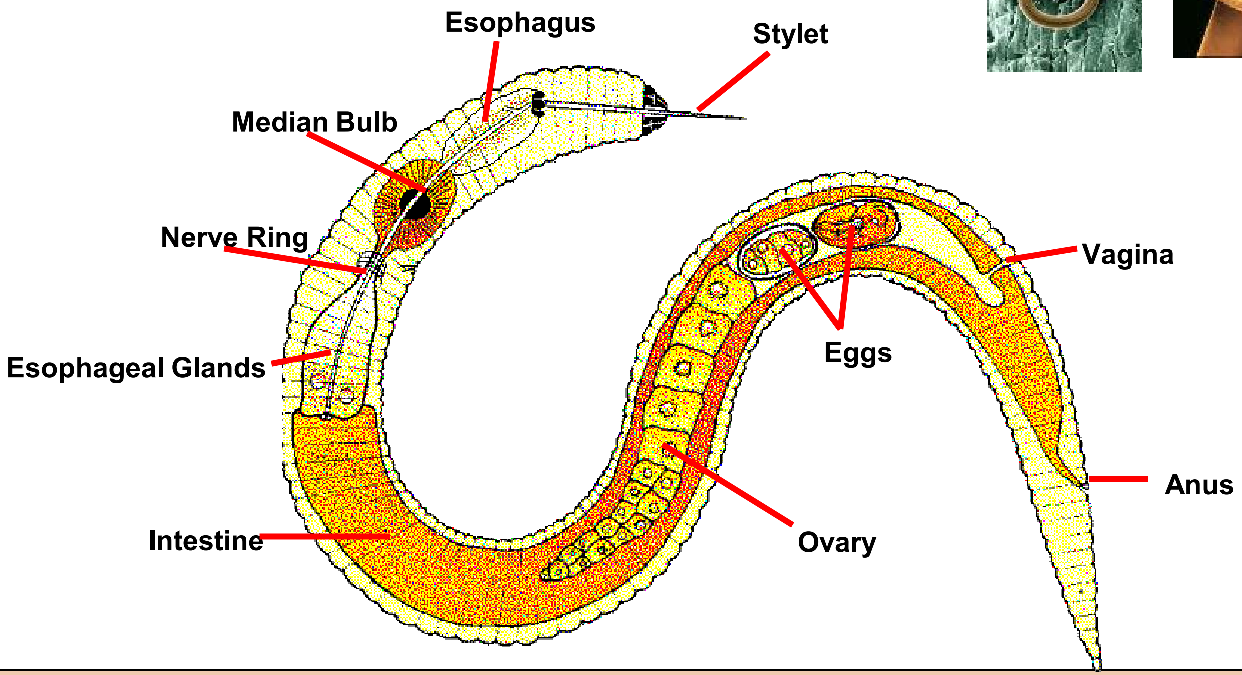
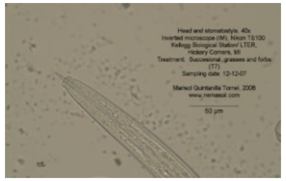
Plant-parasitic nematode



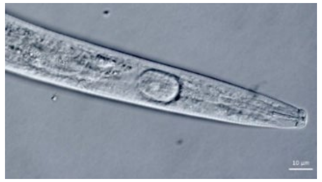
- Transparent and microscopic ~ long, thin roundworms ('threadworms' or 'eelworms')
- At the head is a hollow <u>mouth spear</u> (~ hypodermic needle) called a stylet
- **Feed by piercing and sucking** - Punctures plant cells, withdraws food, secretes protein and metabolites

Predator

Bacterivore

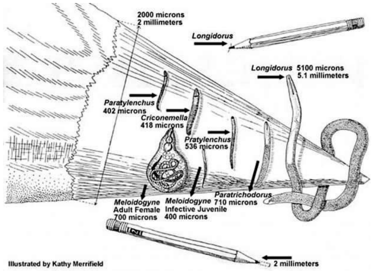


Omnivore



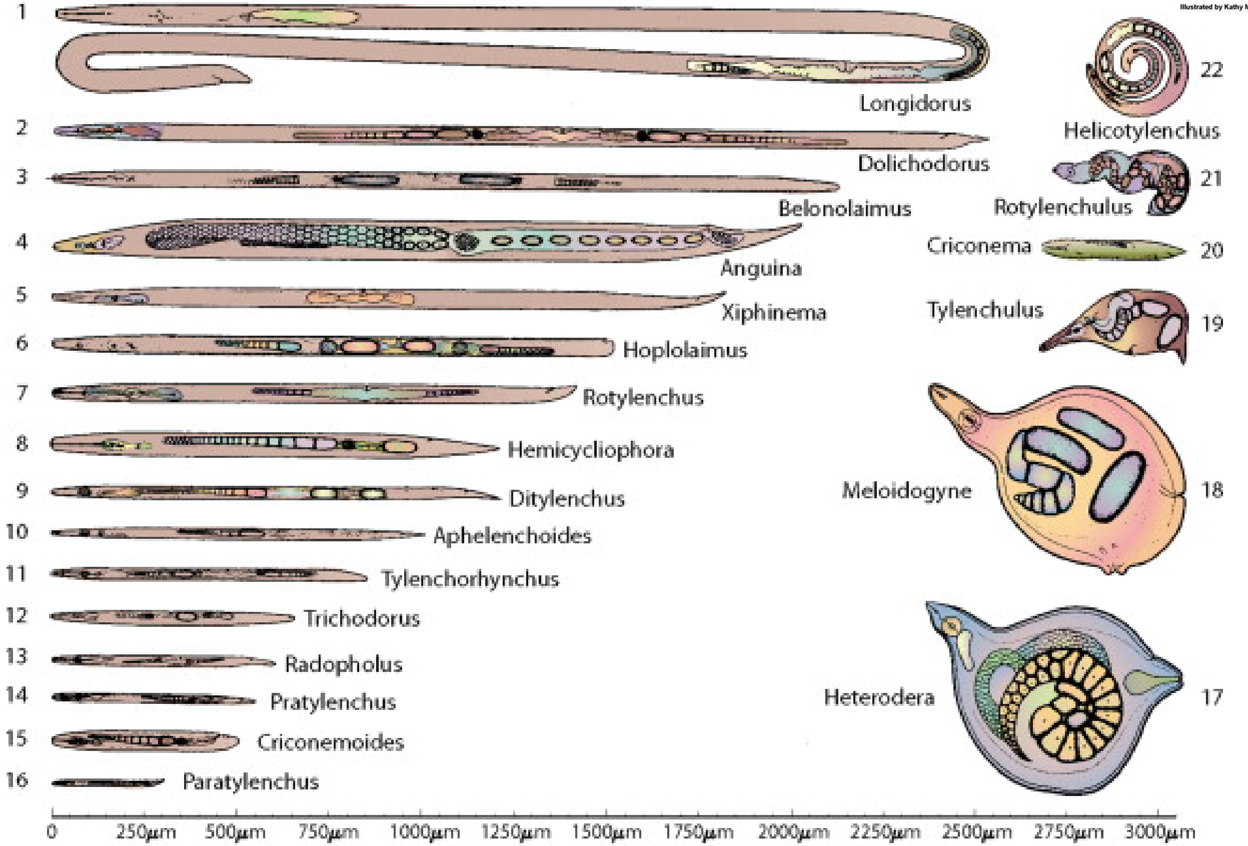
Fungivore

Relative sizes of plant-parasitic nematodes



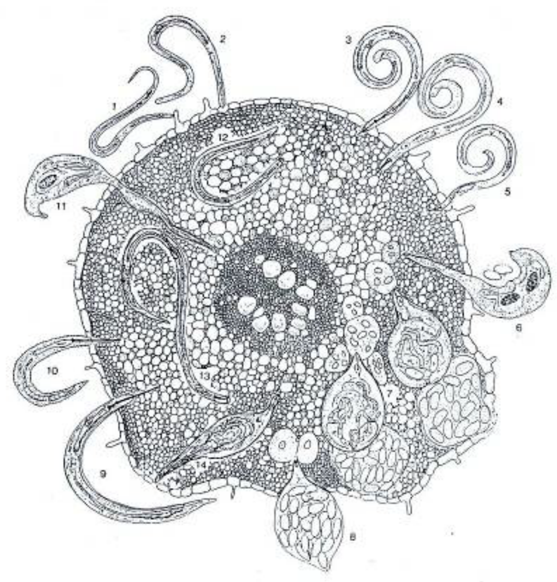
1/4 inch

1/60 inch



credit Society of Nematologists

Nematodes Feed on Roots in Different Ways



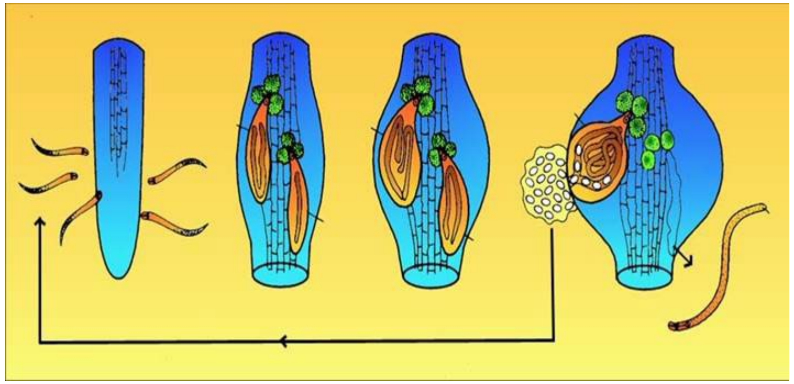
- Endoparasitic– entire body inside the root – *root-knot, cyst, lesion*
  - Sedentary – mostly immobile during their life ex. *root-knot and cyst*
  - Migratory – mobile for all their life – *lesion*
- Semi-endoparasitic- part of body inside root - *reniform*
- Ectoparasitic– entire body outside the root - *sting*

Root-knot nematodes (*Meloidogyne* spp.)

- **#1 nematode in Florida + the world, many crops**

- **Endoparasitic - Root galls**







Florida vegetables – a root-knot paradise made in plastic

M. incognita and *M. enterolobii* on pepper

Root-knot-Fusarium wilt on tomato

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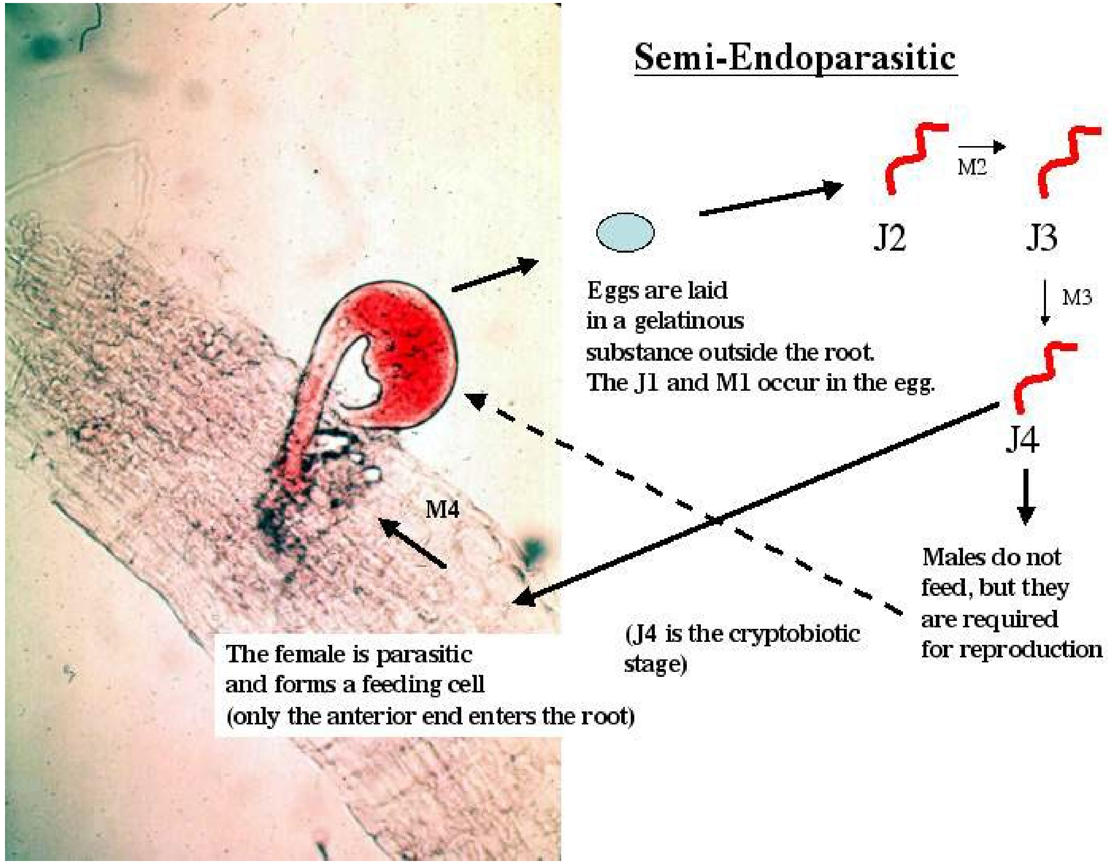
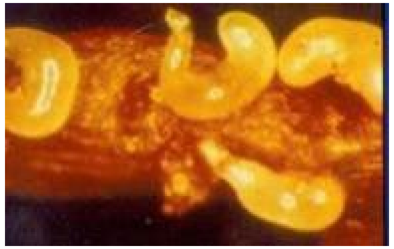
Reniform nematode (*Rotylenchulus reniformis*)

Sedentary semi-endoparasite – part of the body inside the root





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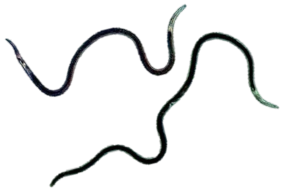
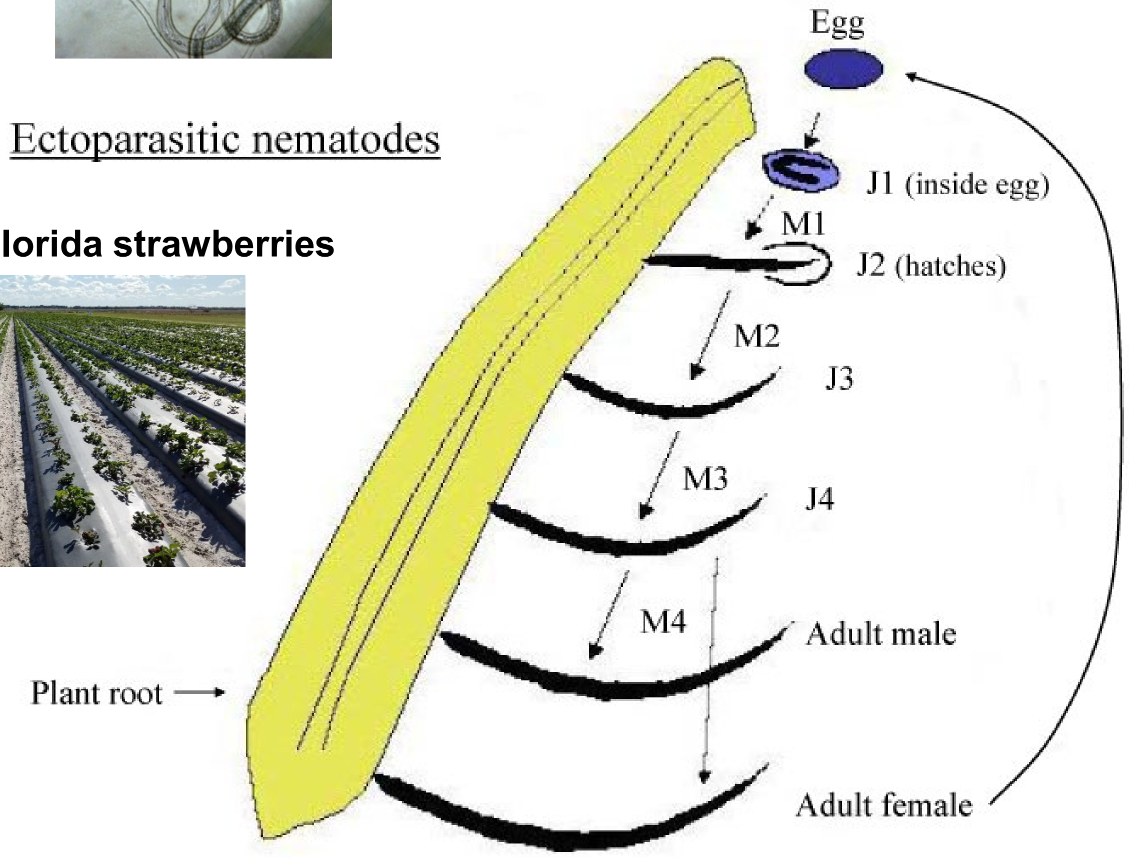
Sting nematode (*Belonolaimus longicaudatus*)



Ectoparasitic– entire body outside the root

1 nematode in Florida strawberries



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Sting nematode on organic broccoli in Florida

Aboveground and belowground symptoms of sting nematode damage to broccoli in Florida

Stunted plants and severely pruned root system

Cabbage less damage?

Soil type has major impact on nematode damage potential

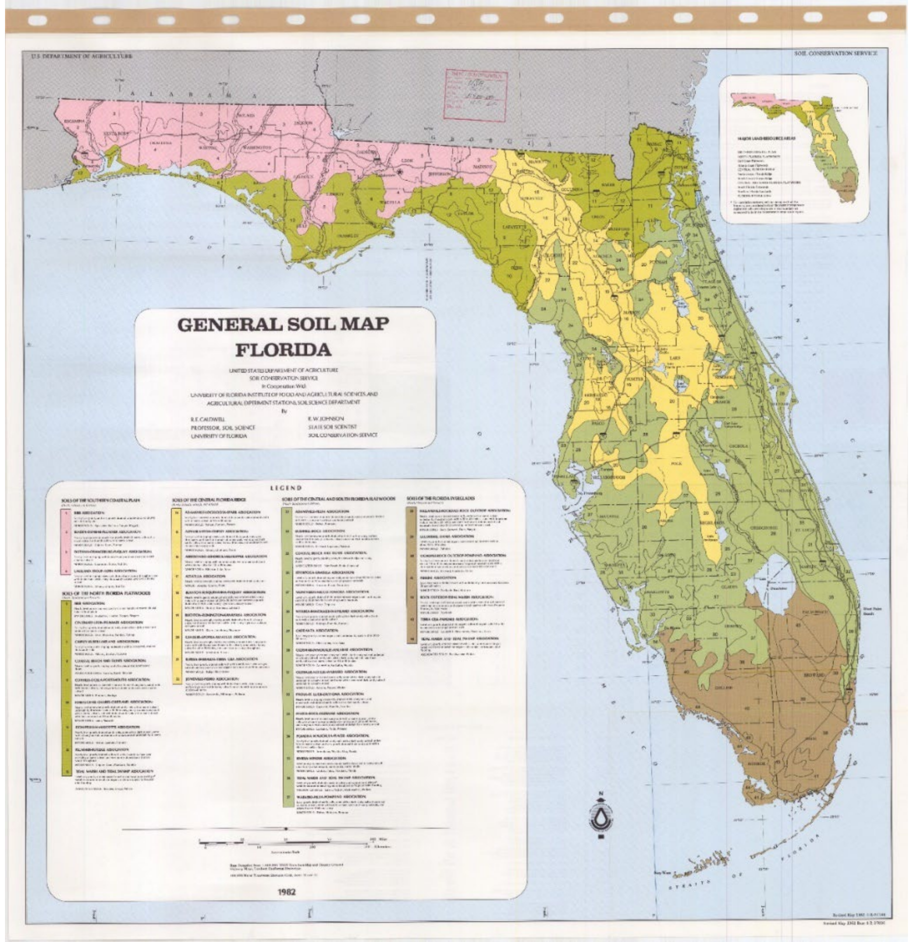
Yellow and green: sand (90-100%)

- majority of nematode problems

Brown color: organic soils

- rarely nematode problems

Pink color: sandy on top clay below



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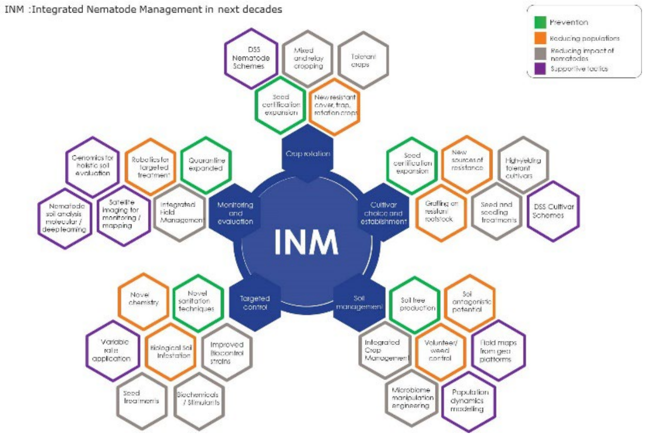
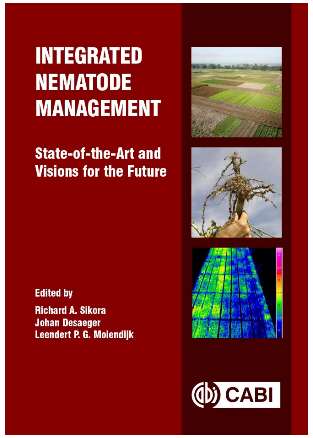
Ideally nematode management is an integrated approach

Five Pillars of Integrated Nematode Management





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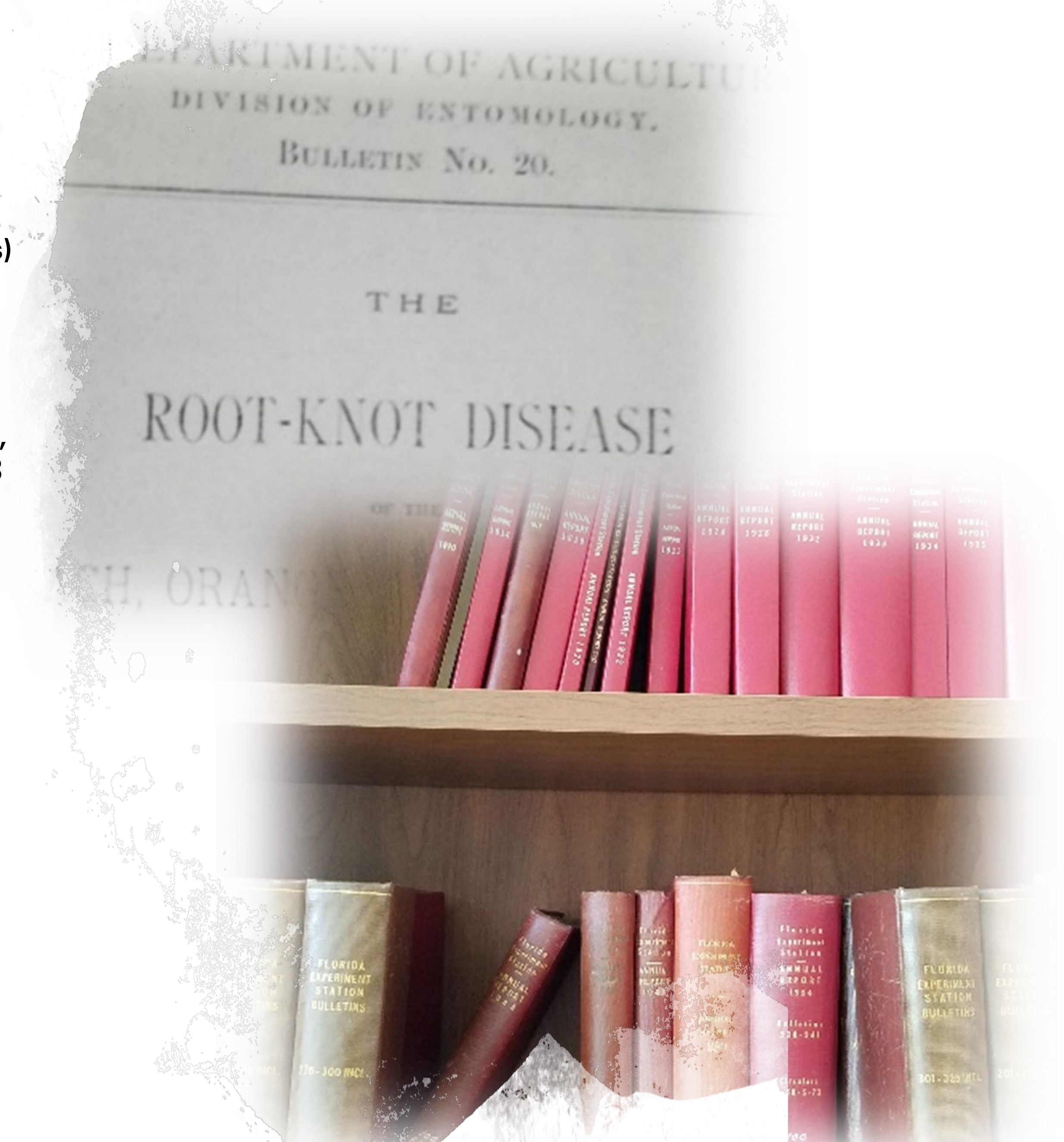
Nematode Management in Florida 1890-1940s (Neal, Watson and Brooks)

- **Burning** crop residues**; summer fallow**, frequent plowing, without weeds; **trap crops** completely destroyed after 2-3 weeks; **resistant crops** in rotation; **sterile subsoil** to fill planting holes
- **Cover crops** (velvet bean (*Mucuna pruriens*), *Crotalaria* spp., …) heavy **mulching**; applications of **cyanamid** (+ other alkaline fertilizers), non susceptible **root stock** (plum for peach)
- **Heavy fertilizing**, closely set rows of trees , damp locations increase disease severity
- **Weed hosts** such as portulaca, Chenopodium, amaranthus, artemisia
- For the homegarden – penning hens “scratching and wallowing”
- Observation on **fire ants** –”pulling the enlarged worms from the decaying tissue and devouring them …”



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Nematicides Historic Overview

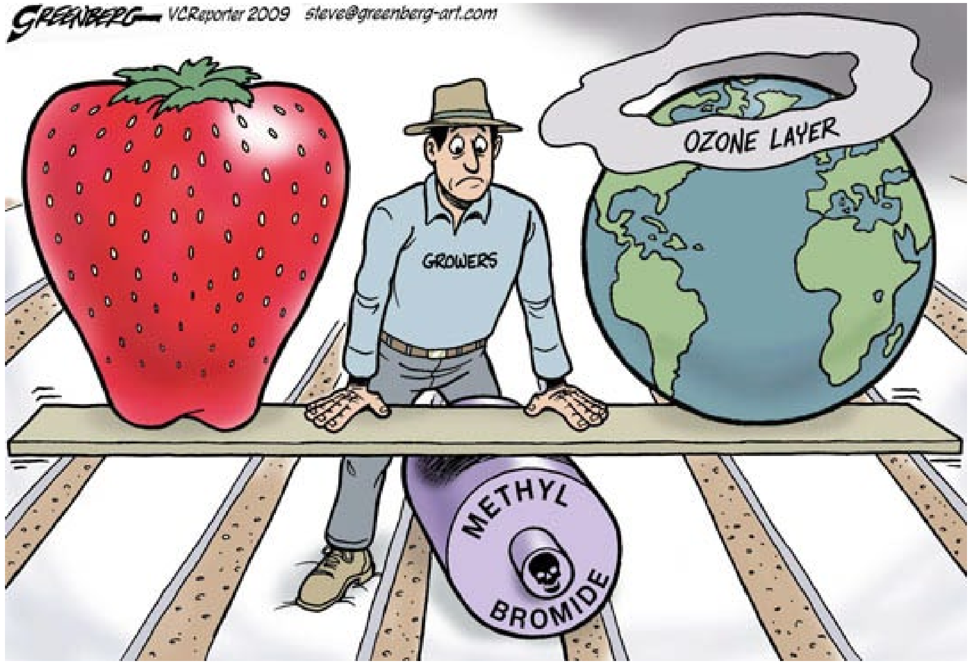
Products that have been used as nematicides throughout history

(red, green and yellow indicate currently registered in US)

[a]DD = dichloropropane-dichloropropene mixture; EDB = ethylene dibromide; DBCP = 1,2-dibromo-3-chloropropane; 1,3-D = 1,3-dichloropropene; Enzone = sodium tetrathiocarbonate (carbon disulfide liberator); MIT = methyl isothiocyanate; Allyl ITC = allyl isothiocyanate; [b]AChE = Acetylcholinesterase inhibitors; inhibition is reversible for carbamates, and irreversible for organophosphates; GluCl = Glutamate-gated chloride channel allosteric modulators; SDHI = succinate dehydrogenase inhibitors; LBI = Lipid Biosynthesis Inhibitor. [c]*Limited registration; ** no longer available

Common name[a]	First use (Country)	Product type / Chemistry	Mode-of-action[b]	Signal words[c]
Carbon disulfide	1869 (FR)	Fumigant	Multi-site	Danger**
Chloropicrin	1920 / 1936	Fumigant	Multi-site	Danger
Methyl bromide	1932 / 1961	Fumigant	Multi-site	Danger*
Formaldehyde	1930	Fumigant	Multi-site	Danger**
DD, EDB, DBCP	1943-1954	Fumigant	Multi-site	Danger**
1,3-D	1954	Fumigant	Multi-site	Danger
Metam sodium	1954	MIT generator	Multi-site	Danger
Fensulfothion	1957	Organophosphate	AChE	Danger**
Ethoprop	1963 (US)	Organophosphate	AChE	Danger
Aldicarb	1965 (US)	Carbamate	AChE	Danger*
Dazomet	1967	MIT generator	Multi-site	Danger
Carbofuran	1969	Carbamate	AChE	Danger*
Fenamiphos	1968 (DE)	Organophosphate	AChE	Danger*
Oxamyl	1972 (US)	Carbamate	AChE	Danger
Terbufos	1974 (US)	Organophosphate	AChE	Danger*
Enzone	1978	Fumigant	Multi-site	Danger*
Cadusafos	1990? (US)	Organophosphate	AChE	Danger*
Imicyafos	2010 (JPN)	Organophosphate	AChE	Danger*
Fosthiazate	1992 (JPN)	Organophosphate	AChE	Danger*
Abamectin	1981 (JPN)	Lactone	GluCl	Danger
Spirotetramat	2008 (US)	Tetramic acid	LBI	Caution
Dimethyl Disulfide	2010 (US)	Fumigant	Multi-site	Danger*
Methyl iodide	2007 (US)	Fumigant	Multi-site	Danger**
Allyl ITC	2013 (US)	Fumigant	Multi-site	Danger
Tioxazafen	2017 (US)	Oxadiazole	Unknown	Caution*
Fluensulfone	2014 (US)	Thizaole	Unknown	Caution
Fluopyram	2013 (Hon)	Benzamide	SDHI	Caution
Fluazaindolizine	2023	Imidazopyridine	Unknown	Caution
Cyclobutrifluram	?	Carboxamide	SDHI	Caution

Florida vegetables, strawberries > soil fumigation standard



Since ban on methyl bromide, the use of chloropicrin, 1,3-D and metam has increased significantly

Broad-spectrum biocides aimed at ‘cleaning up’ the soil

Hazardous, expensive … not very sustainable

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Fumigation often gives a positive and visible growth response

Fumigated bed (1,3-D + chloropicrin) (left) versus non-fumigated bed (right), GCREC

Double-cropping common in plasticulture

- Save investment on plastic and drip tape
- Often done when first crop didn't make enough money
- Many different crops, cucumber, squash cantaloupe, watermelon, pepper, eggplant, corn
- Cucurbits most common, usually direct-seeded
- Root-knot nematodes often major problem

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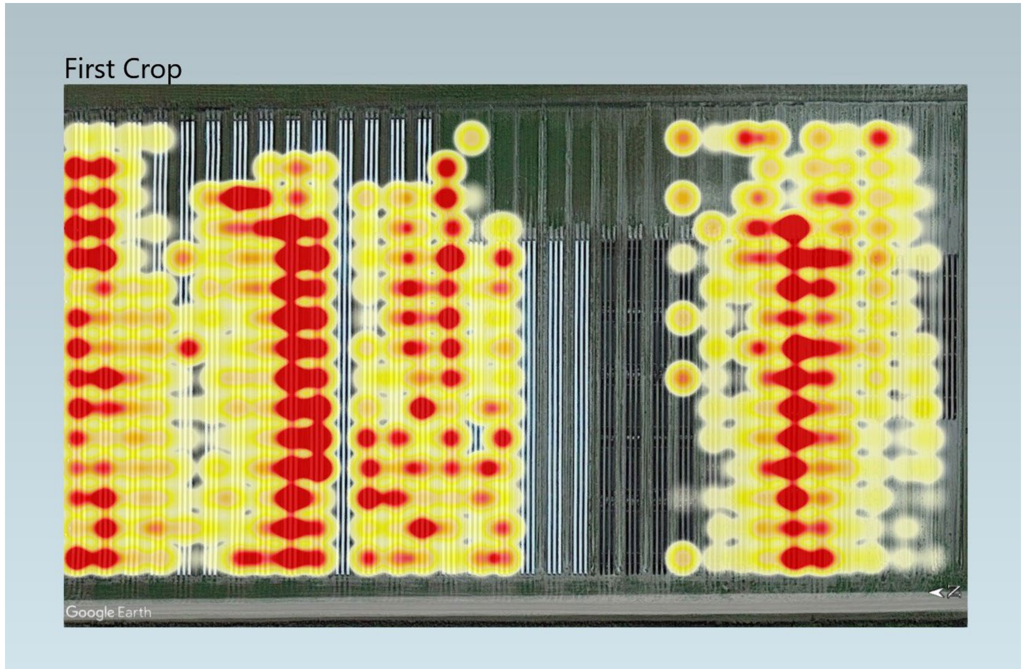
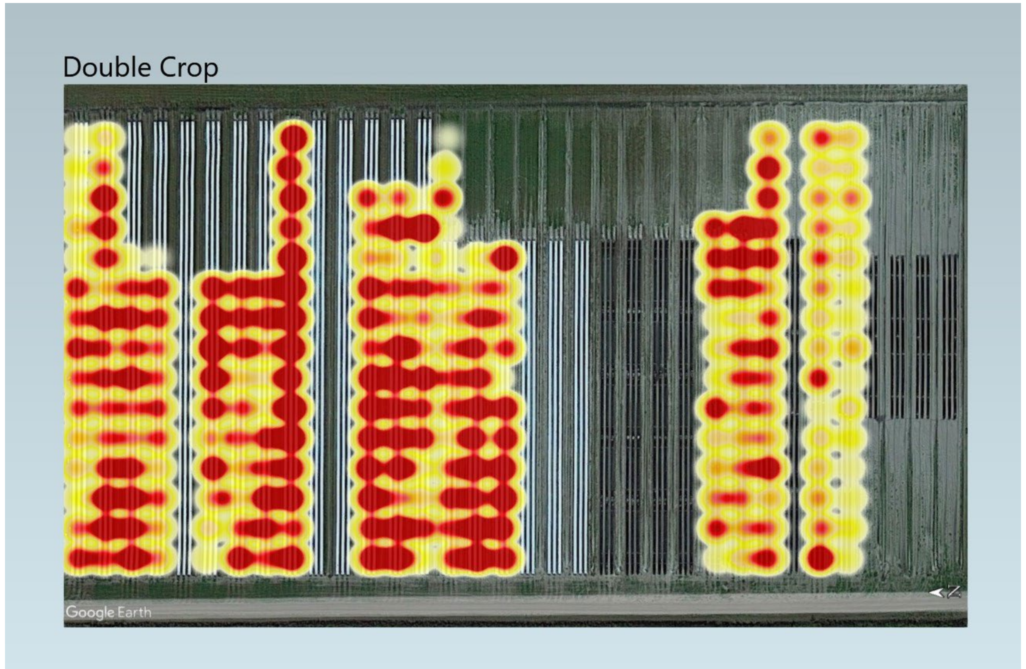
Nematode hot spots in 1st and 2nd crop

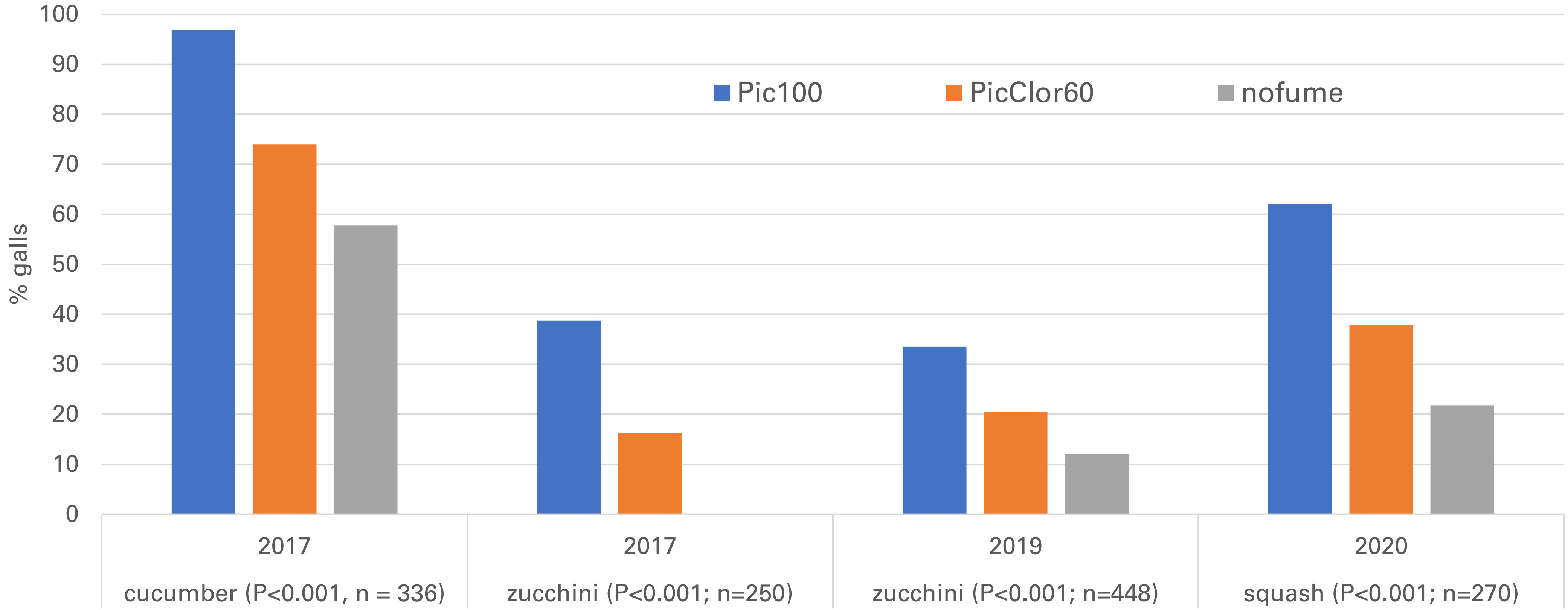
(based on historic root gall ratings; GCREC farm, nematode research field, Justin Carter)





Field mapping / monitoring is an important component of INM

Root-knot damage at the end of the season on cucurbit double crops as affected by fumigation (Pic100, PicClor60 or no fumigant) on the first crop (tomato)



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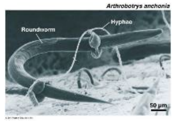
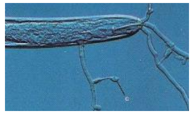
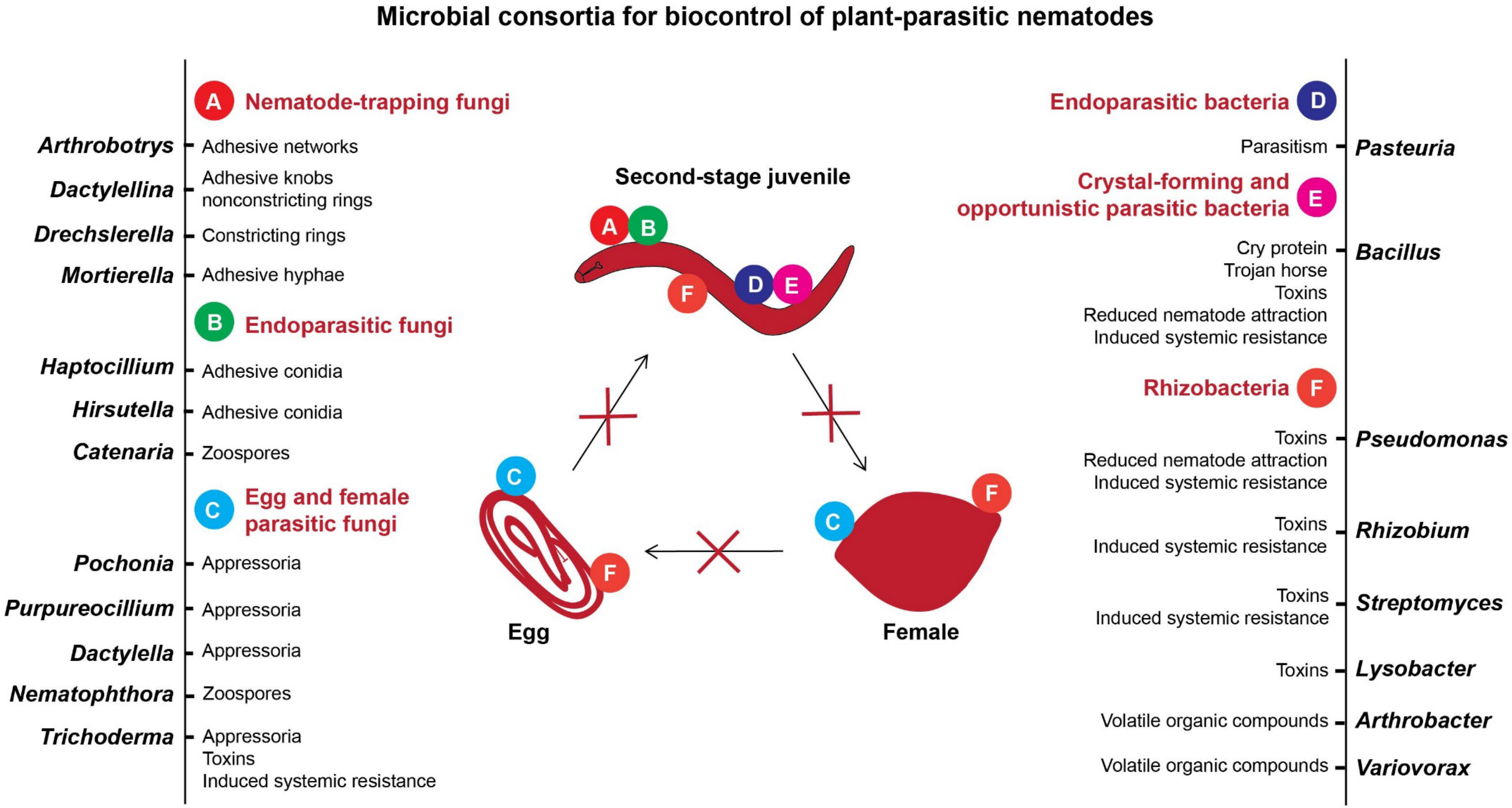
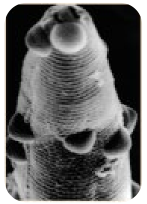
Many fungi and bacteria have potential as nematode biocontrol agents









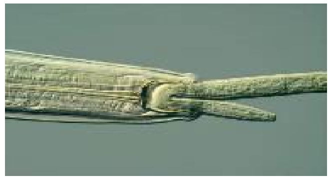
Topalovic et al, 2020
https://doi.org/10.3389/fmicb.2020.00313

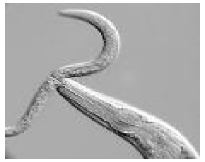
Soil Management -↑ organic matter to stimulate nematode suppressiveness

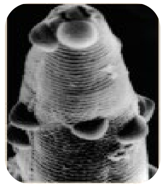
(survey from different agricultural fields across FL)

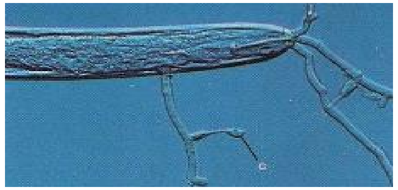
Location	OM %	Crop	Management	Suppressiveness (%)#	Bacterial Diversity	Fungal Diversity
Site 1	1.0	Strawberry	Organic	50.0 a	5.74 a	3.64 a
Site 2	1.3	Strawberry	Organic	53.9 a	5.83 a	3.81 a
Site 7	0.3	Strawberry	Conventional*	25.5 b	5.60 b	3.02 b
Site 8	3.4	Natural Ecosystem	-	43.6 a	5.50 b	4.47 a

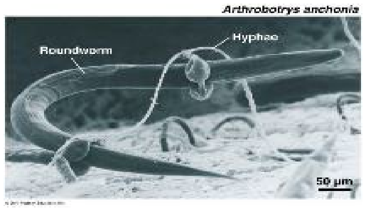
- * Fumigated for past 20+ years;
- # measured with root-knot bioassay on cucumber











- Greatest suppressiveness in organic strawberry and natural ecosystem
- Reduced bacterial and fungal diversity in conventional strawberry (Dr. Sarah Strauss, UF)

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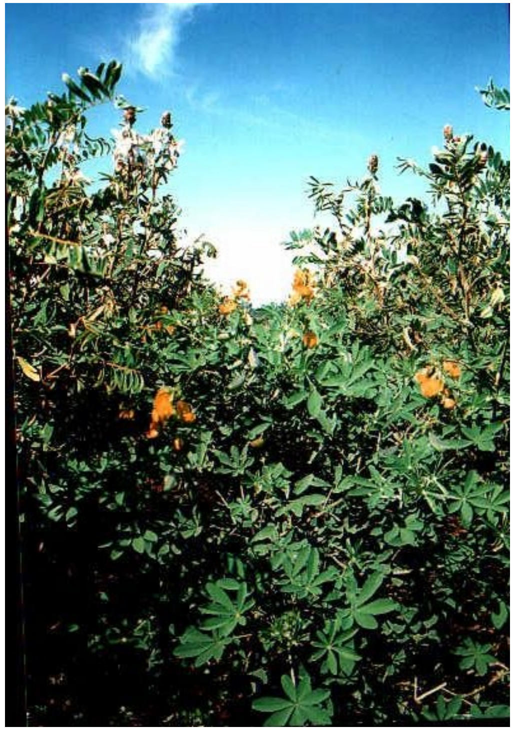
Crop rotation / cover crops as nematode management tool



- Cover Crop is a non-host
- Cover Crop is used as a "Trap Crop"
- Cover Crop has toxic root exudates or breakdown products
- Activity in the Soil Food Web is increased

Cover crops in early Florida agriculture

Men standing in a field of velvet beans (Mucuna), 1932 (top), 1914 (bottom)

Man kneeling next to growth of Crotalaria (1933)

Man standing in a field of Crotalaria striata (1924)

Cowpea (ca 1900)

Crotalaria intermedia (left) and C. spectabilis (right) cut and gathered for silage and seed (1933)

Man standing in field of beggarweed (Desmodium) (1917)

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Host suitability of summer cover crops

Bui and Desaeger,
University of Florida

Nematode reproduction (RF = number fold nematode increase after 8 weeks)					
Root knot Nematode species	**Plant species**				
	Sunn hemp	Sorghum Sudangrass	Sunflower	Cowpea	Tomato
M. javanica	0 ± 0	0.02 ± 0.01 B	28.70 ± 10.06 A	67.28 ± 7.09 A	50.54 ± 6.42 A
M. incognita	0 ± 0	0.79 ± 0.31 A	16.73 ± 1.66 A	0.82 ± 0.32 C	33.10 ± 2.83 B
M. enterolobii	0 ± 0	0.00 ± 0.00	3.24 ± 0.86 B	14.09 ± 3.18 B	23.73 ± 2.69 B
M. arenaria	0 ± 0	0.00 ± 0.00	9.33 ± 3.39 AB	2.57 ± 0.63 C	20.50 ± 3.65 B




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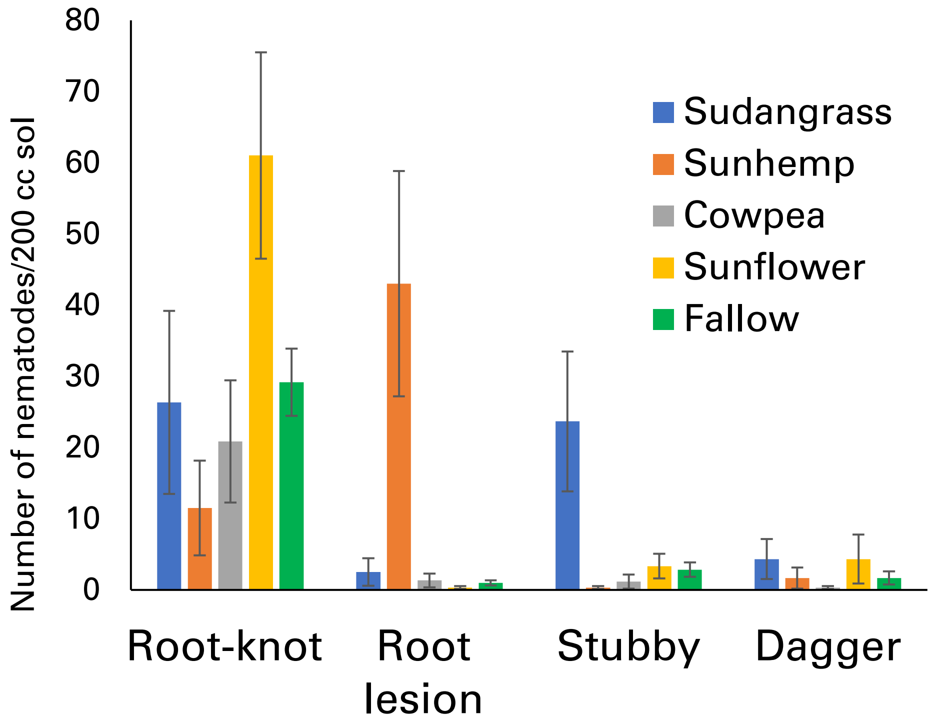
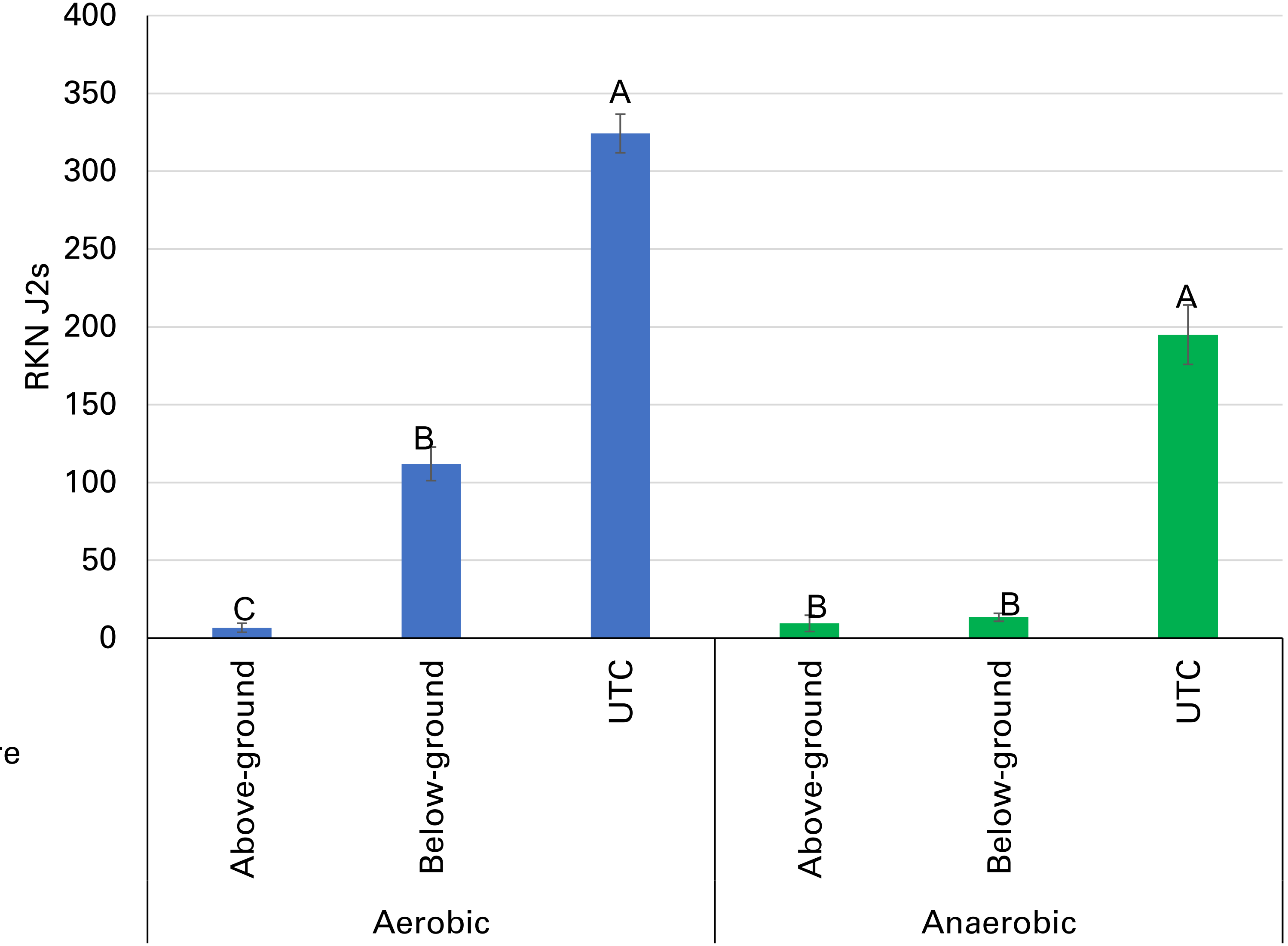
Other nematodes and cover crops in Florida

- **Root-knot nematodes**
  - ↓Sunnhemp and sorghum sudangrass
  - ↑Sunflower
  - ↑ cowpea (depending on cv. and nematode sp.)
- **Sting nematode**
  - ↓ Sunnhemp
  - ↑Sorghum sudangrass
- **Stubby root nematodes**
  - ↑Sorghum sudangrass
- **Lesion nematodes**
  - ↑Sunnhemp and sorghum sudan



Are Sunn hemp breakdown products toxic to nematodes?

The experimental design from left to right: untreated control, soil mixed with the below-ground part, and soil mixed with the above-ground part of sunnhemp. Two conditions were tested: aerobic and anaerobic.



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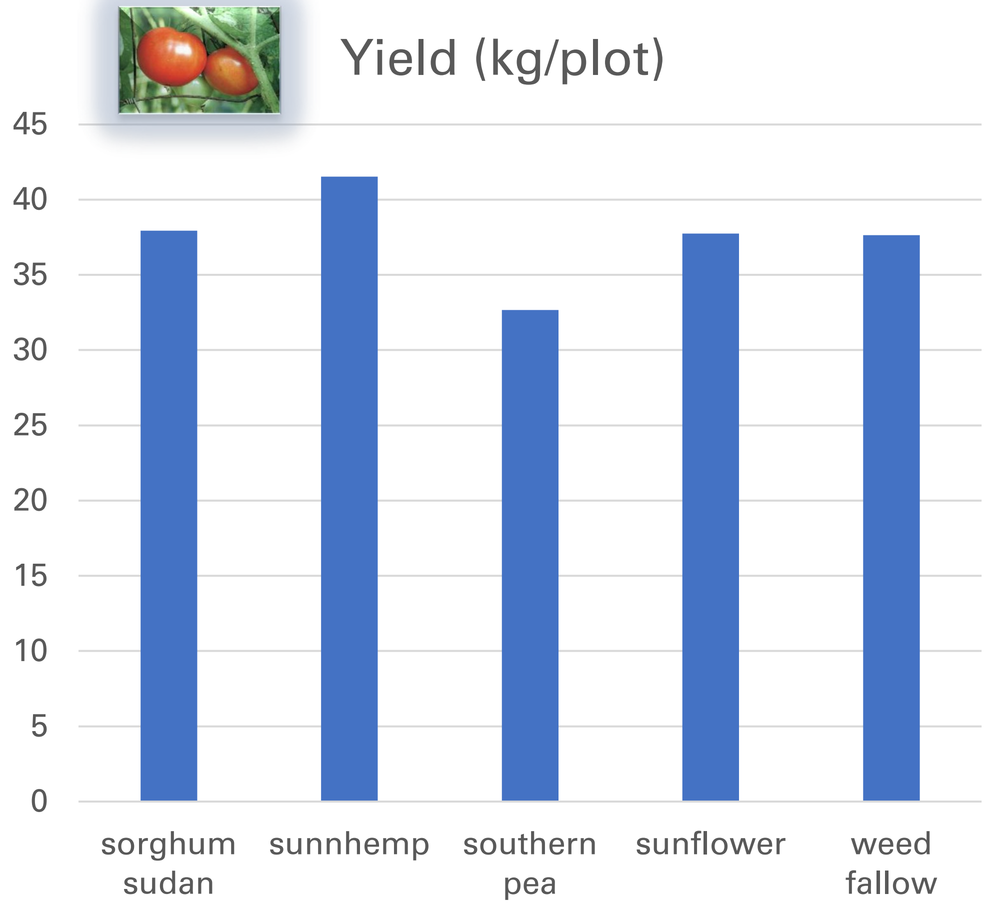
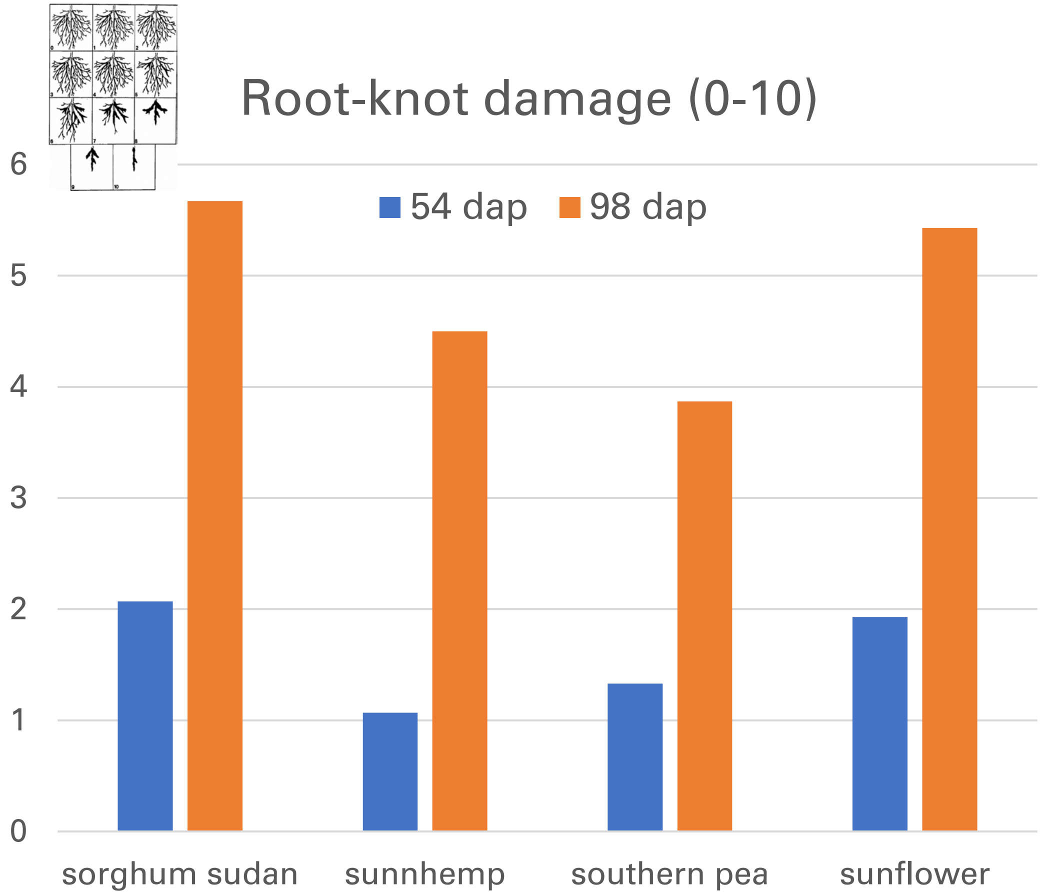
Tomato yield and root-knot damage after summer cover crops, GCREC

Greatest yields in sunn hemp plots and lowest root-knot damage in sunn hemp and southern pea plots





$P < 0.05$

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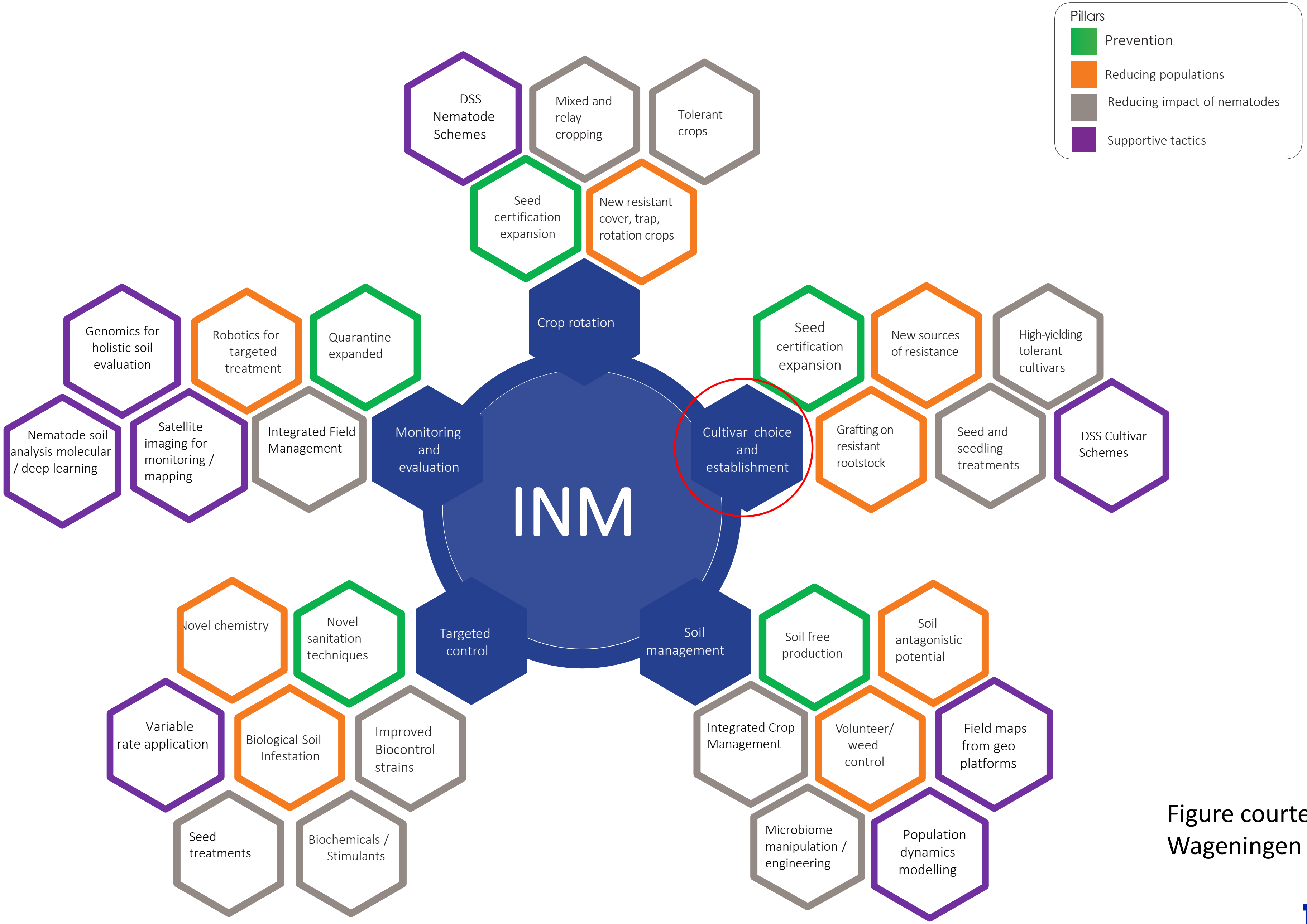

Figure courtesy of Wageningen University

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https://www.cabi.org/bookshop/book/9781789247541/

Resistance and tolerance – mostly root-knot and cyst

Tomato Tasti-Lee with Mi (A) and w/o Mi gene

Host plant	Gene or source	*Meloidogyne* spp.
Carrot	*Mj - 1*	Mi, Mj
Clover	*TRKR*	*M. trifoliophila*
Coffee	*Mex - 1*	*M. exigua*
Common bean	*Me 1, Me2, Me 3*	Mh, Mi, Mj
Cotton	*Rkn 1, RKN2*	Mi
Cowpea	*RK, Rk2, rk3*	Ma, Mh, Mi, Mj
Grape	*N, Mur1*	Ma, Mi
Lucerne	*Mj - 1*	Mh, Mi
Lima bean	*Mir -1, Mig- 1, Mjg- 1*	Mi, Mj
Groundnut (peanut)	***Arachis* spp. hybrids**	**Ma, Mj**
Pepper	*Me1, 3,4,7; Mech1,2*	Ma, Mi, Mj, *M. chitwoodi*
Potato	*Rmc1, MfaXIIspI*	*M. chitwoodi*, Mh, *M. fallax*, Mi
Prunus (peach)	***Ma***	**Mj, Mi, Ma, Mf**
Soybean	*2 QTLs*	Mj
Sugarbeet	*Beta vulgaris* spp.	Ma, *M. chitwoodi, Mh, M. fallax*
Sweet potato	*Mi, Mj, Ma*	
Tobacco	*Rk*	Mi
Tomato	***Mi1 – Mi9***	**Ma, Mi, Mj**
Wheat	*Triticum tauschii*	Mi, Mj, *M. chitwoodi*

Resistant tomato cv's not widely used in Florida (unlike CA > majority of processing tomato are Mi-resistant cultivars)

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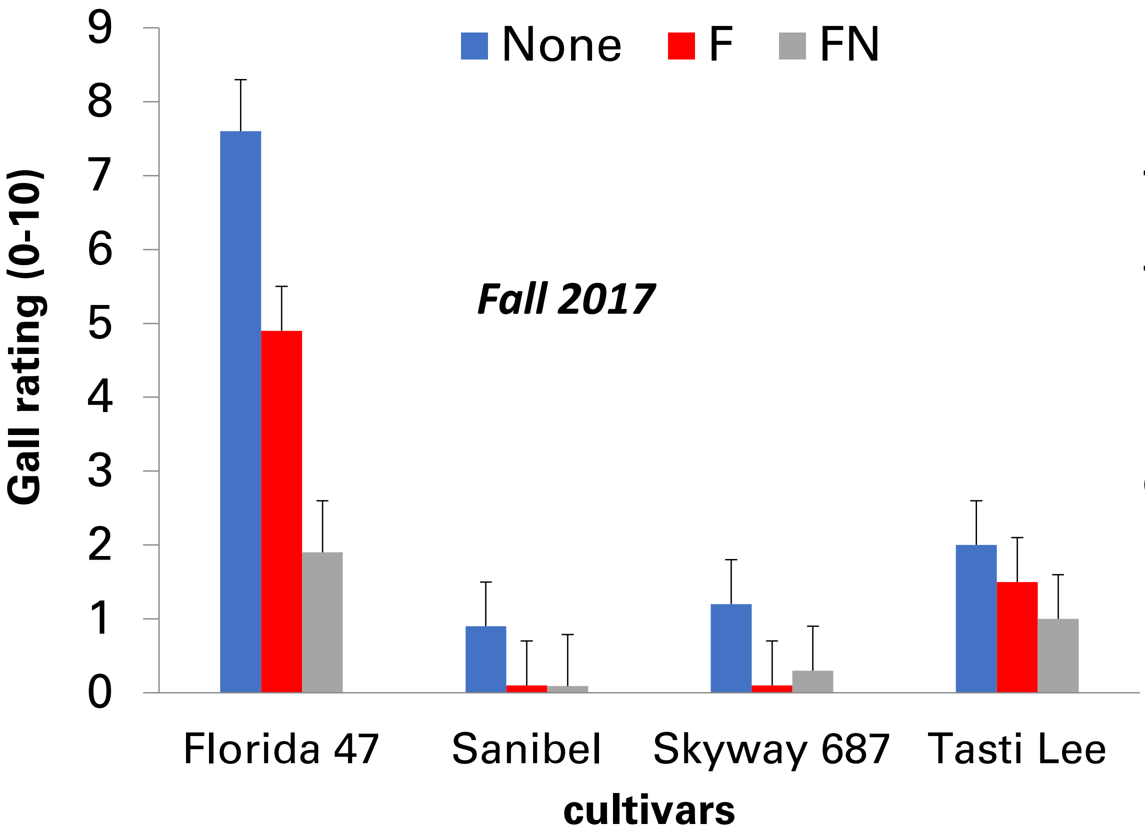
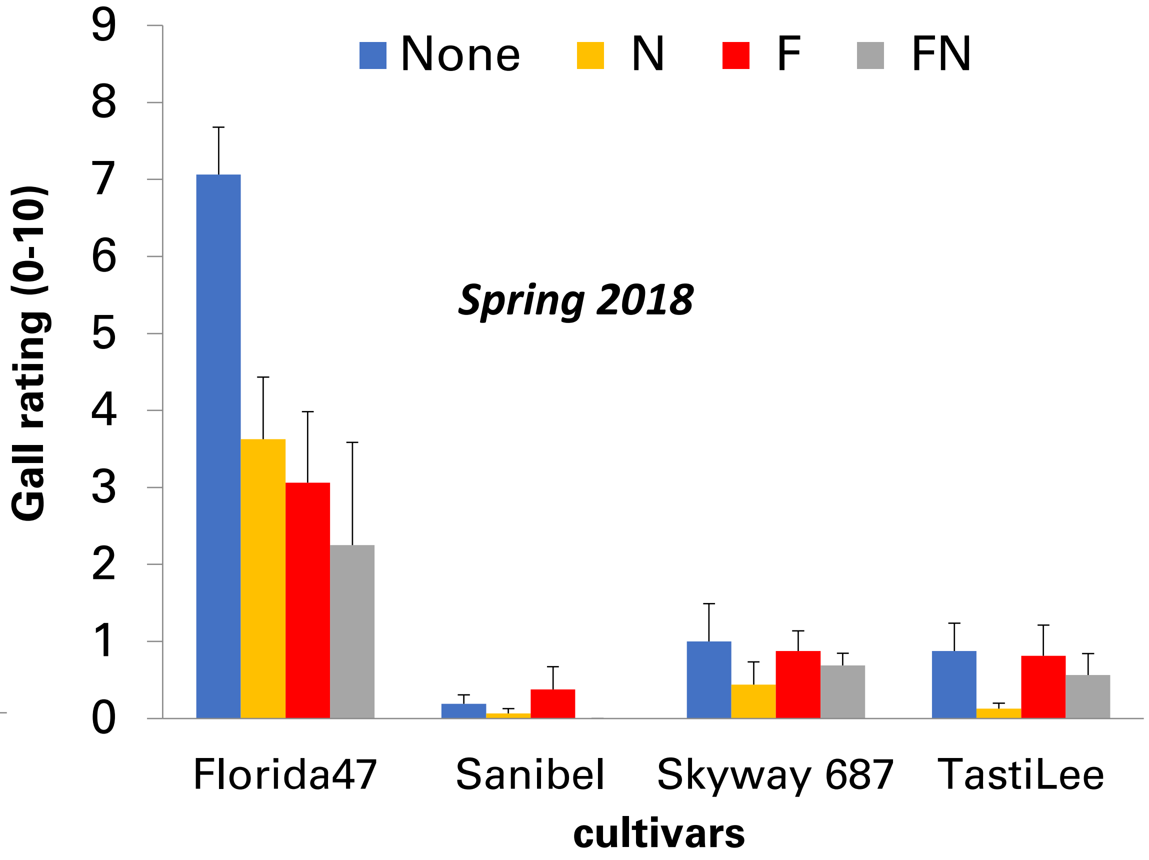
Mi tomatoes significantly reduced root-knot damage both seasons

No temperature effect on *Mi* (soil temp often > 90 F)



P cultivar <0.0001; P fumigant < 0.01; P nematicide NS



P cultivar <0.0001; P fumigant = 0.01; P nematicide = 0.03

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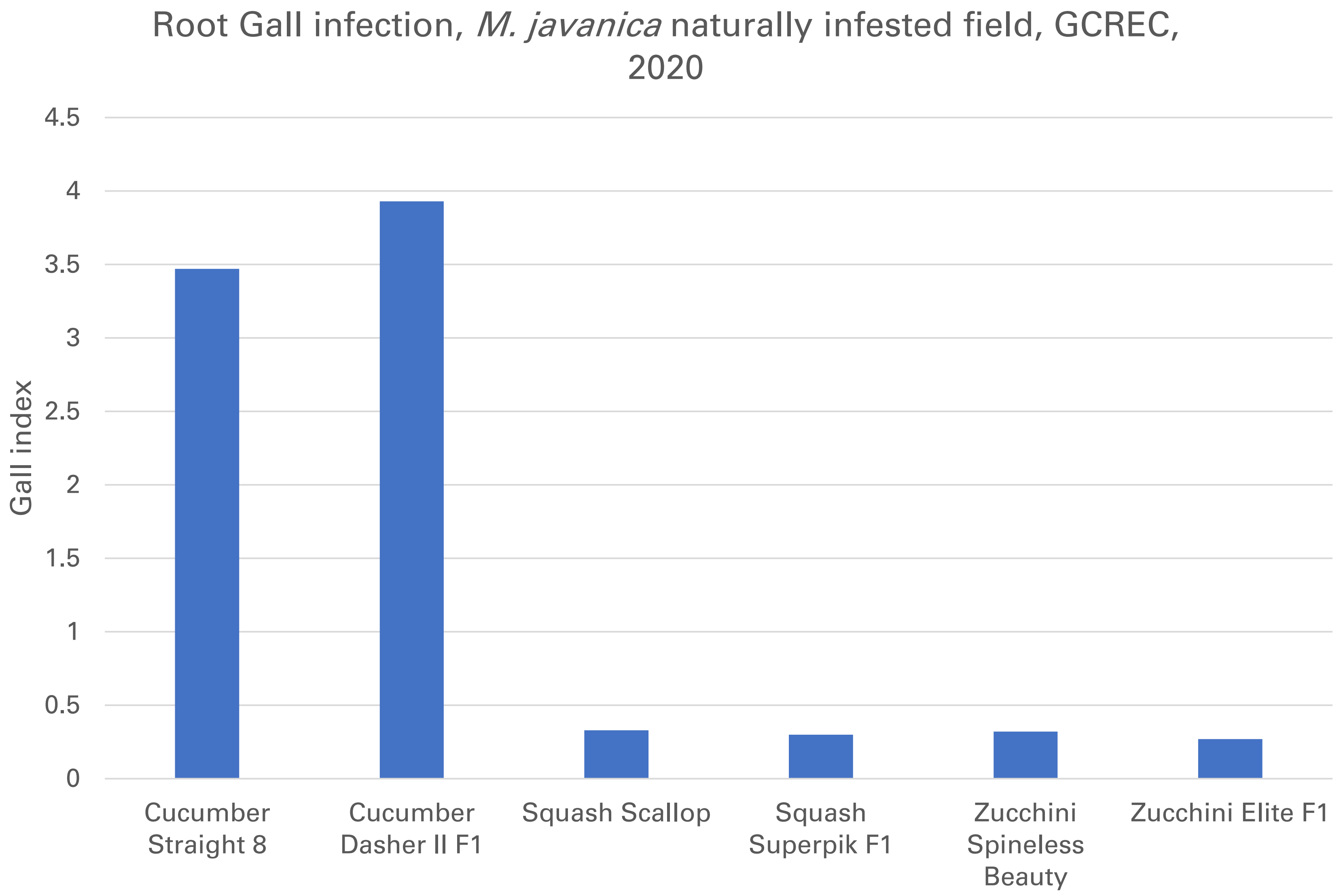
No resistant cucurbits yet but squash and zucchini less root damage than cucumber



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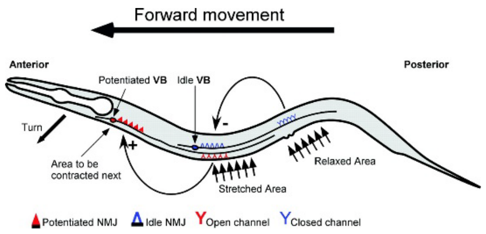
Sanitation – nematodes mostly spread passively

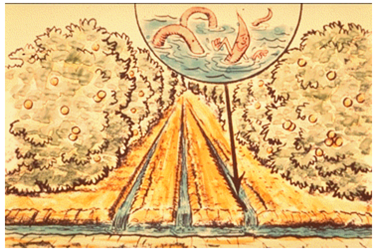
Within a field: short distance

Active movement in soil water, few feet



Across fields: longer distance

Passive movement with water, wind, animals, farm equipment, plant and root debris


Across states/countries:

Passive movement via shipments of plants, tubers, bulbs, seeds, soil, wood





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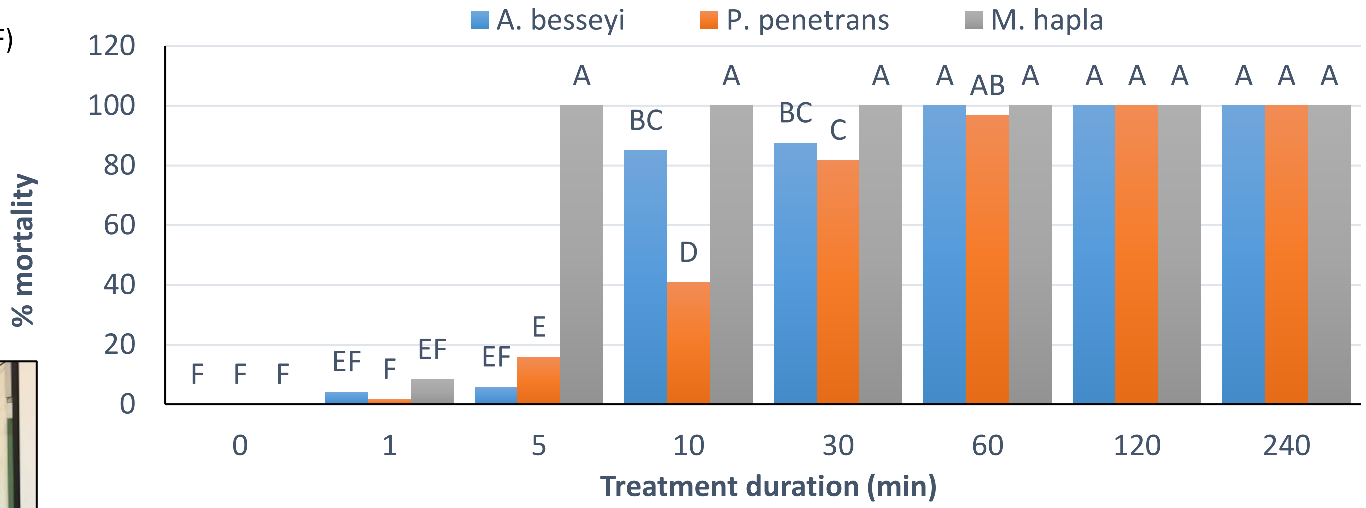
Nematode-free planting stock

- Heat Treatment or Thermotherapy is a widely-used non-chemical strategy
  - Hot water treatment of bulbs dates back to 1869
  - Hot water can be harmful to plant material, esp. strawberry plants
- Aerated steam instead of water (N. Peres, UF)
  - Less damaging to plants
  - Less risk of spreading microbial and nematode pathogens

Heat sensitivity of three main nematodes on strawberry transplants (water, 44°C, evaluation 24 h after exposure)



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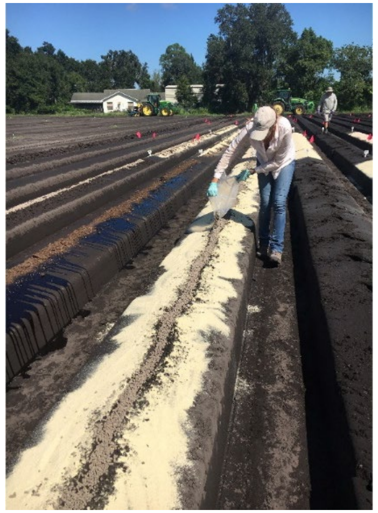
Other non-chemical soil disinfestation: Soil heating – solarization or steaming – Flooding - ASD

Solarization - GCREC crew laying clear solarization plastic – 4-8 weeks, soil should be moist

Soil steaming - tractor with a boiler that heats steam to more than 300 degrees F. Ten-inch spikes inject steam into the ground (Fennimore, UC)



FLOODING TO CONTROL ROOT-KNOT NEMATODES By LLOYD N. BROWN (USDA) (1933, J. of Agric. Research) Four months' submergence of soil killed the larvae, but the eggs remained viable. About 4 months of submergence kills root-knot larvae, but not eggs (2 years needed)

Anaerobic soil disinfestation (ASD), known also as biological soil disinfestation (BSD) is a pre-plant non-fumigant soil disinfestation practice first developed in Japan and the Netherlands (2000)

Dry (rice bran, wheat bran) and liquid (ethanol, molasses) carbon sources can be used to provide a substrate for the rapid proliferation of facultative anaerobic bacteria under saturated soil conditions

The process results in a combination of changes in the soil microbial community composition, production of volatile organic compounds, and the generation of lethal anaerobic conditions (soil heating can enhance efficacy)

(Erin Rosskopf, USDA, FL)

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Recent years > increase in organic crops in Florida

- Florida and southern US slow to adopt organic production > currently highest growth in US
    - Fruits and vegetables …

- Organic strawberry production growing (~ 10% of total area)
    - Strictly organic growers
    - Conventional growers > push from retailers
    - Nematodes are the # 1 problem

- Cost / benefit conventional vs organic
    - No chemical cost, but soil amendments, fertilizer, biopesticides and labor cost higher in organic
    - Higher and more stable price for organic strawberries but lower yield
    - Improved sustainability (soil health, social capital …) … if we can develop effective INM

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Difficulties of working with nematodes:

Patchy irregular field distribution

Movement up and down the soil profile

Seasonal fluctuations

Endo vs ectoparasitic nematodes

Soil and/or root sampling

Different extraction procedures

…

Questions?

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