NC STATE UNIVERSITY

INTEGRATED MANAGEMENT and BIOLOGY OF SOILBORNE PATHOGENS

SAVANNAH, GA
January 5-6, 2022

Presenter: Frank J. Louws
Horticultural Sciences and Plant Pathology
NC-State University

NC STATE UNIVERSITY

College of Agriculture and Life Sciences →

Horticultural Science

THINK AND DO THE EXTRAORDINARY
Support the College →

Factors that have led to the increased expansion of challenges to manage soilborne diseases:

- Intensification; less rotation; increased pathogen inoculum
- reliance on susceptible cultivars to meet specific market demands (e.g. heirlooms)
- global movement & local invasion of novel pathogens
- transition to organics and high tunnels practices
- needs-based practices for resource-limited farmers
- loss of soil fumigants e.g. methyl bromide (MeBr)

The Practice: How soil fumigation benefits the California strawberry industry. Plant Disease 64:264-270. (1980)

Stephen Wilhelm

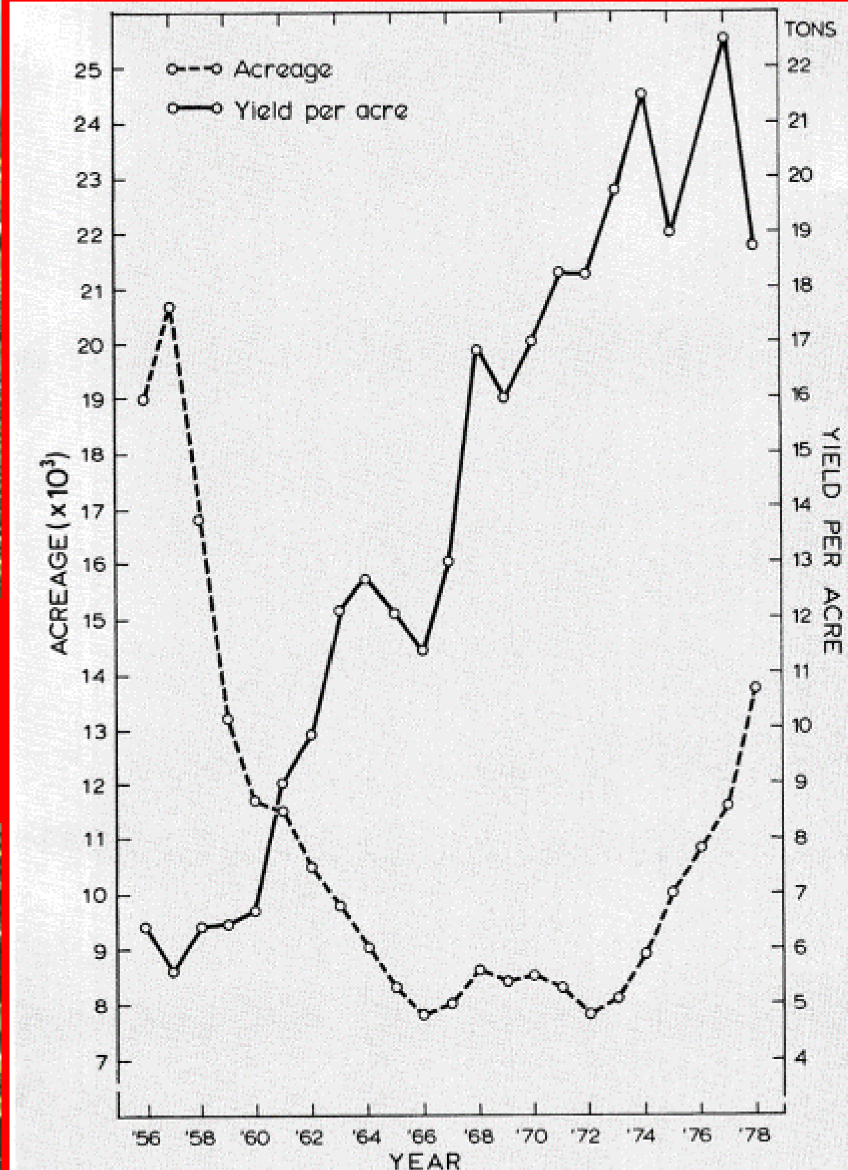
Dr. Wilhelm is professor in the Department of Plant Pathology at the University of California, Berkeley, where he received his Ph.D. in 1948. His research focuses on diseases caused by soilborne, root-infecting fungi, especially Verticillium wilt.

Albert O. Paulus

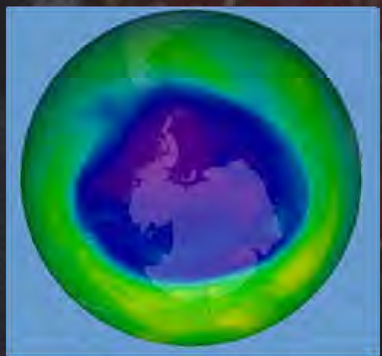
Dr. Paulus is extension plant pathologist in the Department of Plant Pathology at the University of California, Riverside, where he is involved with strawberry, vegetable, and field crop diseases. He received his Ph.D. from the University of Wisconsin in 1954.

19. WILHELM, S., R. C. STORKAN, and J. E. SAGEN. 1961. Verticillium wilt of strawberry controlled by fumigation of soil with chloropicrin and chloropicrin-methyl bromide mixtures. Phytopathology 51:744-748.

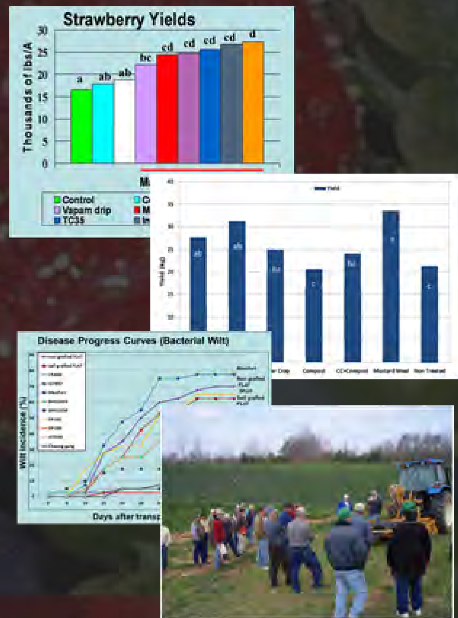
The impact of soil fumigation in California is reflected in the common reference to distinct eras "before fumigation" and "after fumigation" among growers who remember the difficulties and frustrations of strawberry cultivation before the introduction of the soil treatments. Indeed, the two eras of



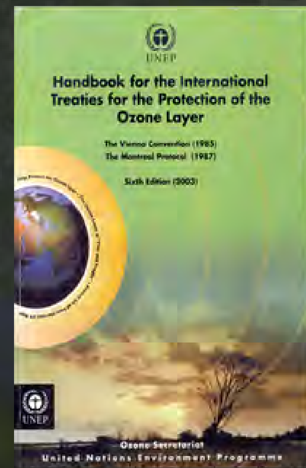
The Big Picture



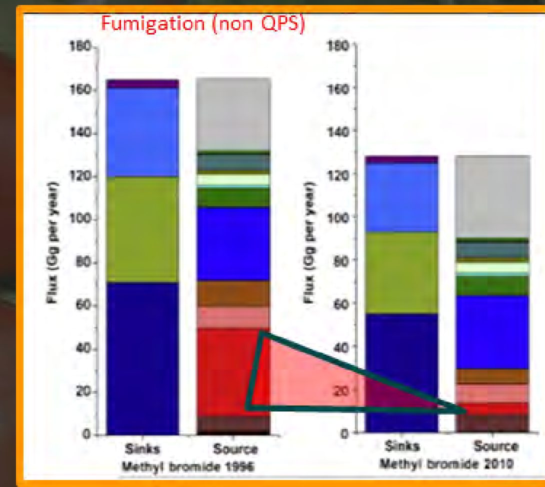
Grand Challenge

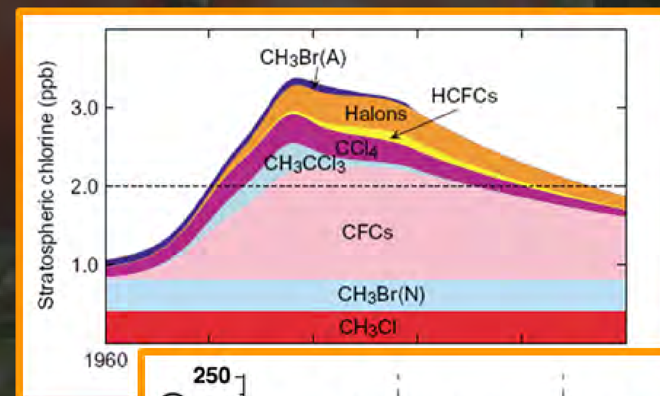


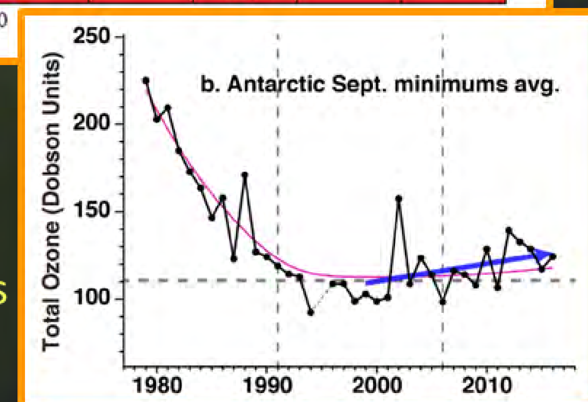
Team Science



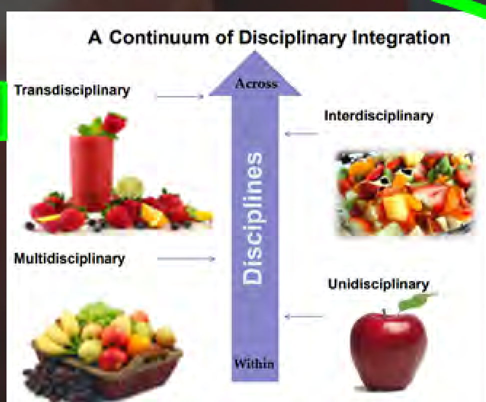
Global Scientific Policy (and collaborations)







Impacts



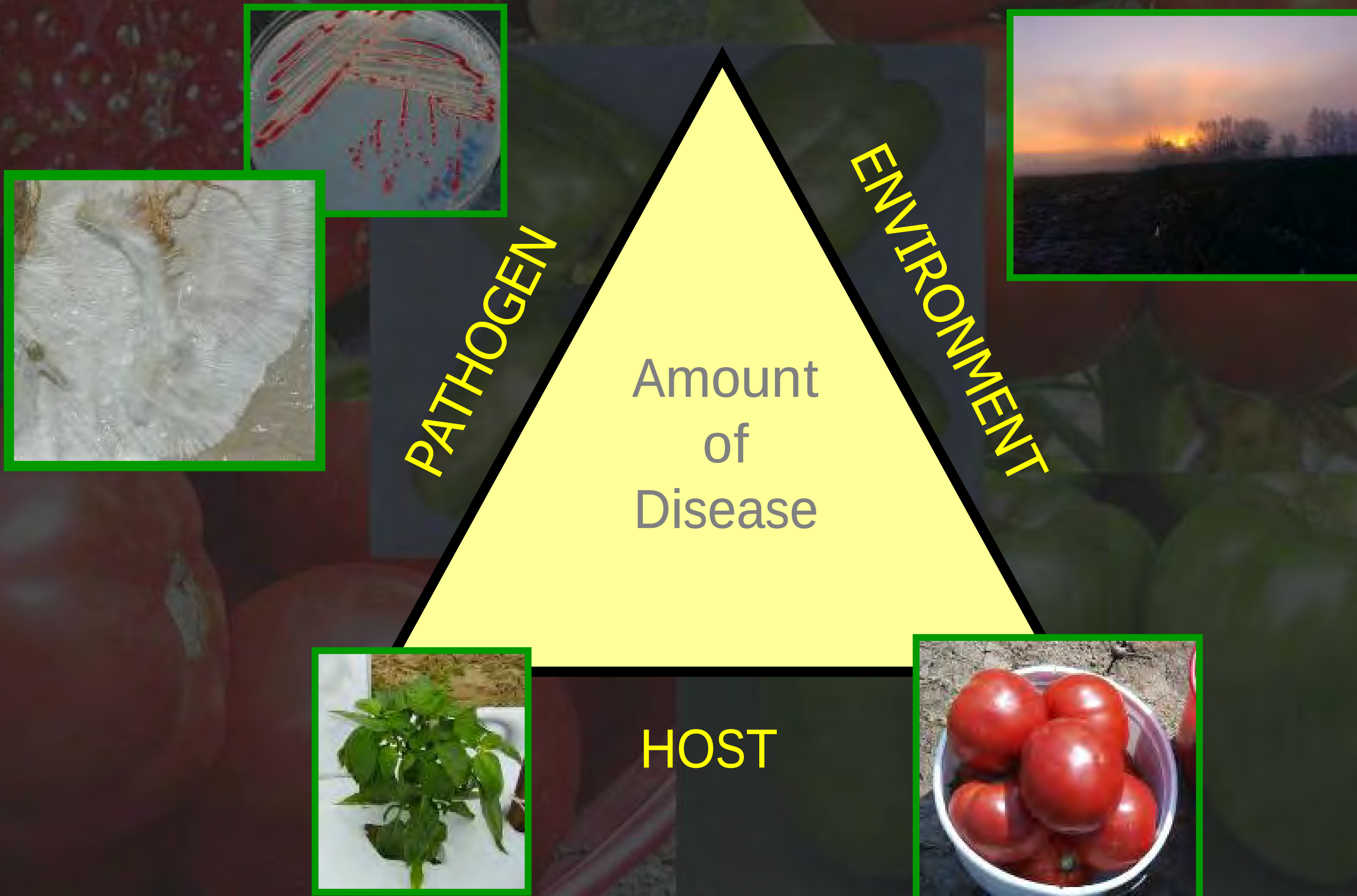
IPM: INTEGRATED PEST MANAGEMENT

A multifaceted approach to managing pests by integrating biological, physical, cultural, chemical, and regulatory tools, as appropriate for specific sites, in a way that optimizes long-term economic, health, and environmental benefits.

$$A + B = X$$

$$\left\{ A \quad C \quad D \quad E \quad F \quad B \right\} X$$

I A. Know Your Biology: The Disease Triangle



I B. Know Your Biology: Common Sources of Inoculum

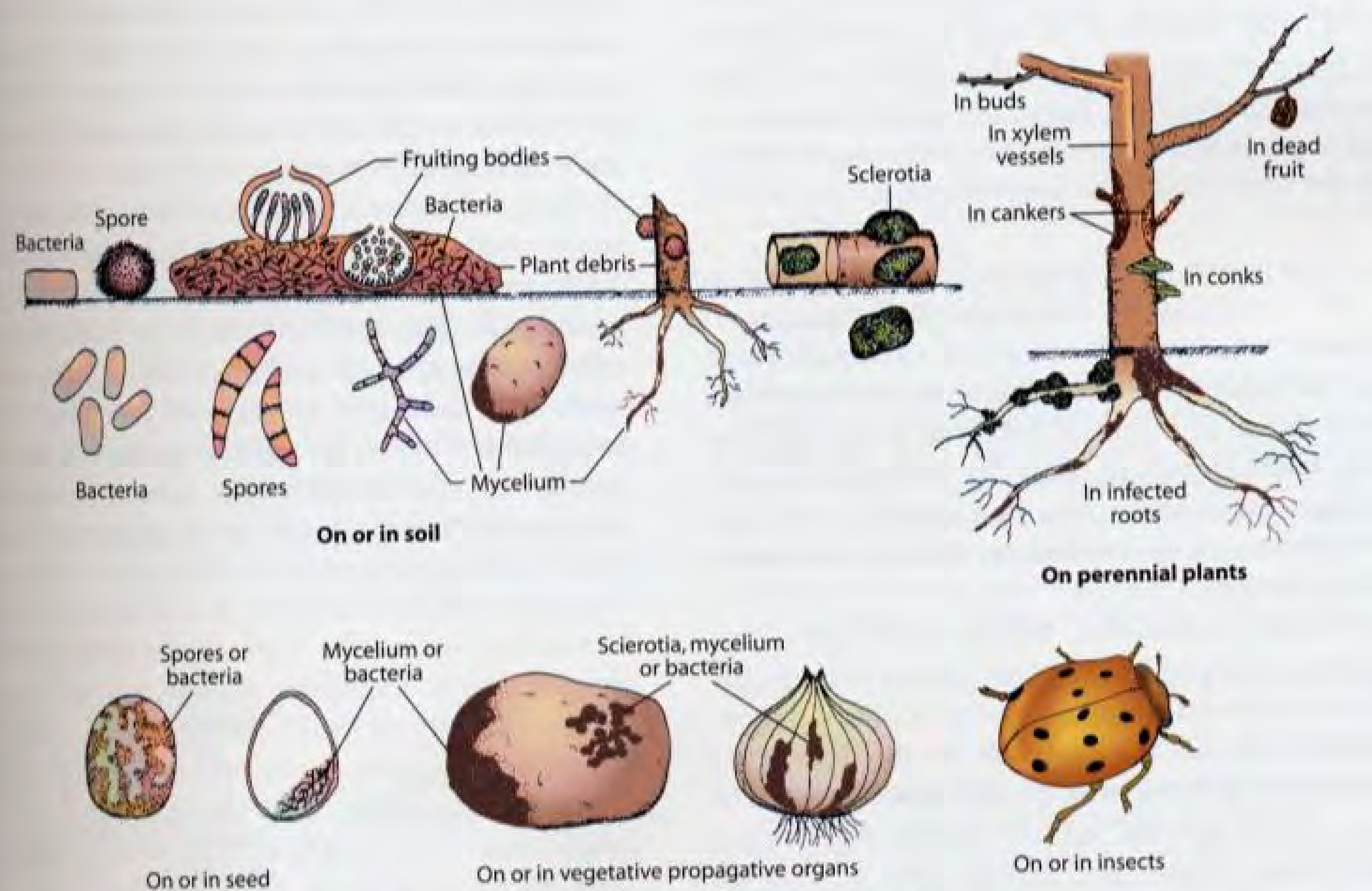


FIGURE 2-21 Forms and locations of survival of fungi and bacteria between crops.

Napoleon "Know Your Enemy"

From: G.N. Agrios. 2005. Plant Pathology. 5th edition. Elsevier AP.

I B. Know Your Biology: Common Sources of Inoculum

1. On or in soil
    a. Soil transients
    b. Soil inhabitants
2. On or in seed or vegetative propagative organs
3. On or in insects (other vectors)
4. On perennial plants, alternative hosts or distant host crops (combined with long-distance transport)

Reference: Agrios pg 80-81; 100-102

I C. Know Your Biology: Pathogen Life Cycles

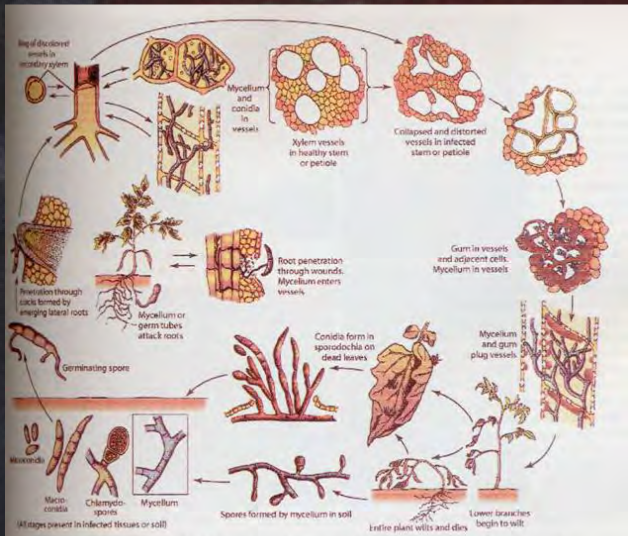
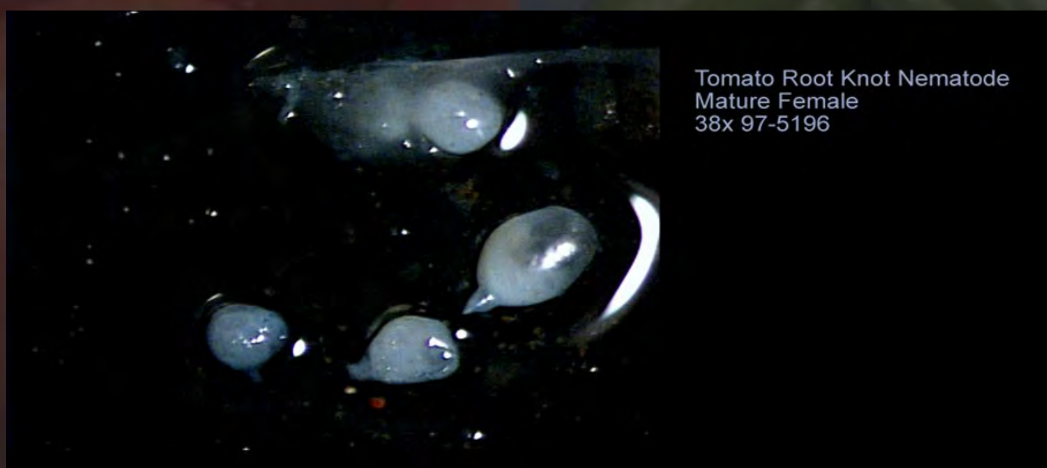


FIGURE 11-105 Disease cycle of *Fusarium* wilt of tomato caused by *Fusarium oxysporum* f. sp. *lycopersici*.



1. Obligate parasite
2. Facultative Parasite
a. non-host-specific
b. host specific

From: G.N. Agrios. 2005. Plant Pathology. 5th edition. Elsevier AP.

II. Know Your Client and Context

- Commercial operation -10 acres or 10,000?
- Home gardener
- Organic or conventional
- Business or life-style oriented
- Owner, manager, extension agent, or consultant
- Experienced or new producer

Diversity of Tomato Production Systems:

MeBr – dependent System

III. DIAGNOSIS CAN BE DIFFICULT:

BUT you (plant pathologists) are uniquely qualified to do it.

Observed SYMPTOMS, SIGNS, and SIGNATURE

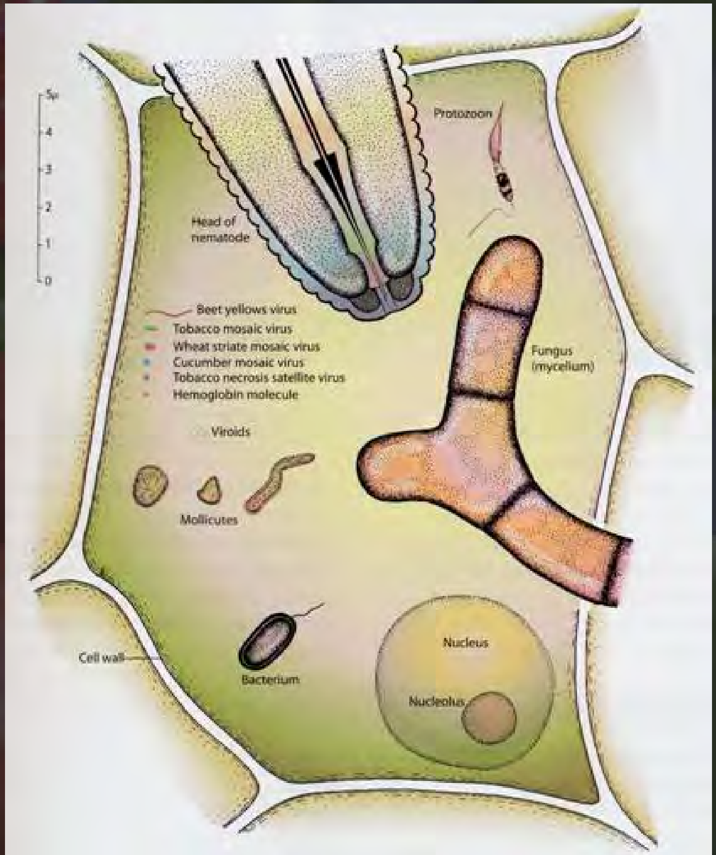


FIGURE 1-2 Schematic diagram of the shapes and sizes of certain plant pathogens in relation to a plant cell. Bacteria, mollicutes, and protozoa are not found in nucleated living plant cells.

From: G.N. Agrios. 2005. Plant Pathology. 5th edition. Elsevier AP.

Signs and Symptoms
And THE Signature

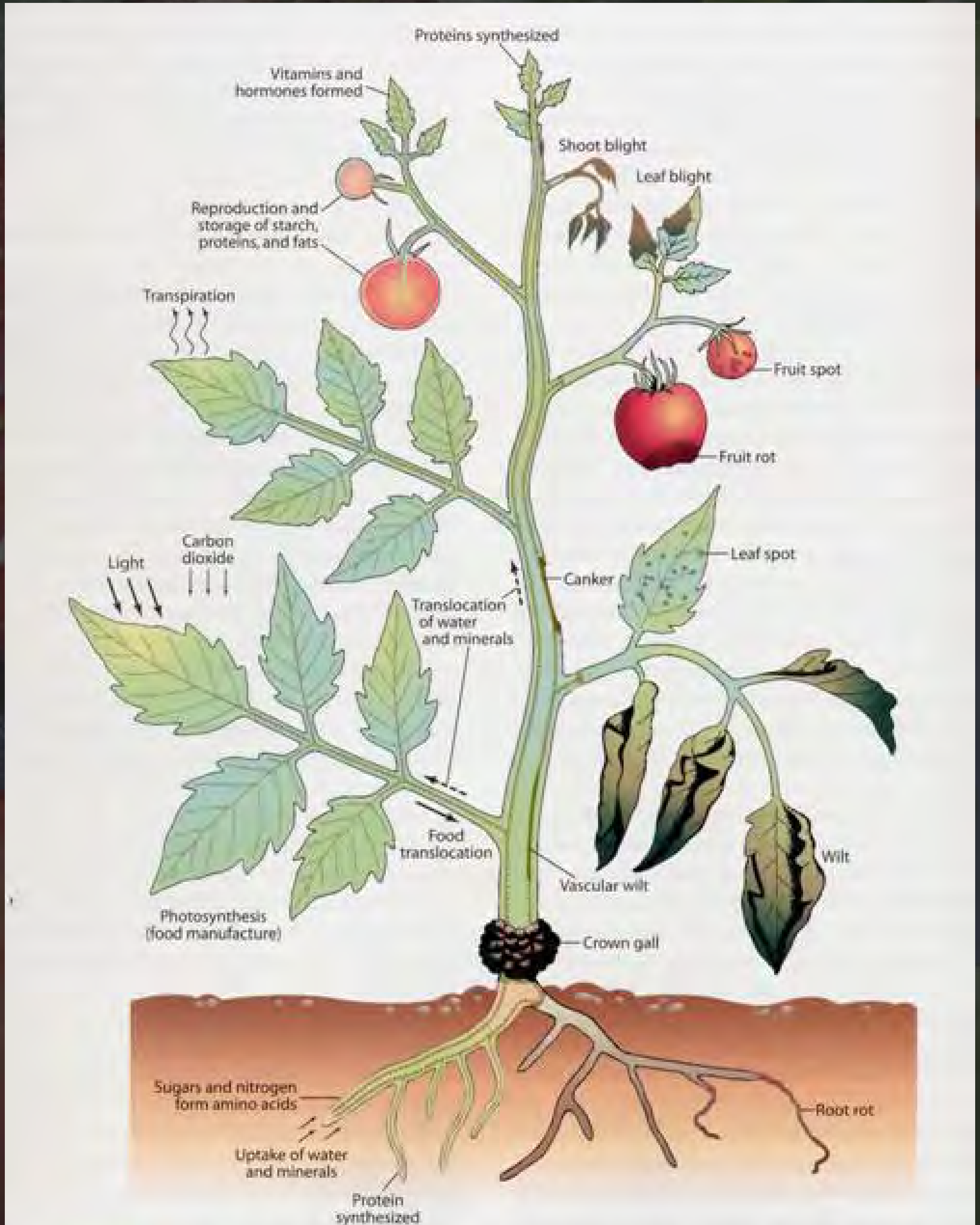


FIGURE 1-1 Schematic representation of the basic functions in a plant (left) and of the kinds of interference with these functions (right) caused by some common types of plant diseases.

Signature - the specific temporal and spatial expression of signs and symptoms (FJL)

From: G.N. Agrios. 2005. Plant Pathology. 5th edition. Elsevier AP.

IV. STEPS IN DIAGNOSIS
NARROW IT DOWN

LIVING FACTOR
BIOTIC
→ { PATHOGEN { FUNGAL, BACTERIA, VIRUS, NEMATODE }
INSECT
OTHER PEST

NON-LIVING FACTOR
ABIOTIC
→ { MECHANICAL
PHYSICAL
CHEMICAL { SOIL pH, SALTS }

USE YOUR RESOURCES!

V. STEPS IN DIAGNOSIS

A. IDENTIFY THE PLANT (HOST)

B. COLLECT KEY INFORMATION

1) Spatial information
2) Temporal Inforamation
3) Husbandry Information
4) Plant information
5) Other information

C. FORMULATE A DIGANOSIS, PROGNOSIS AND RECOMMENDATION


IN PARTNERSHIP WITH
VEGETABLE GROWERS NEWS
SOUTHEASTERN U.S.
2021 VEGETABLE CROP HANDBOOK

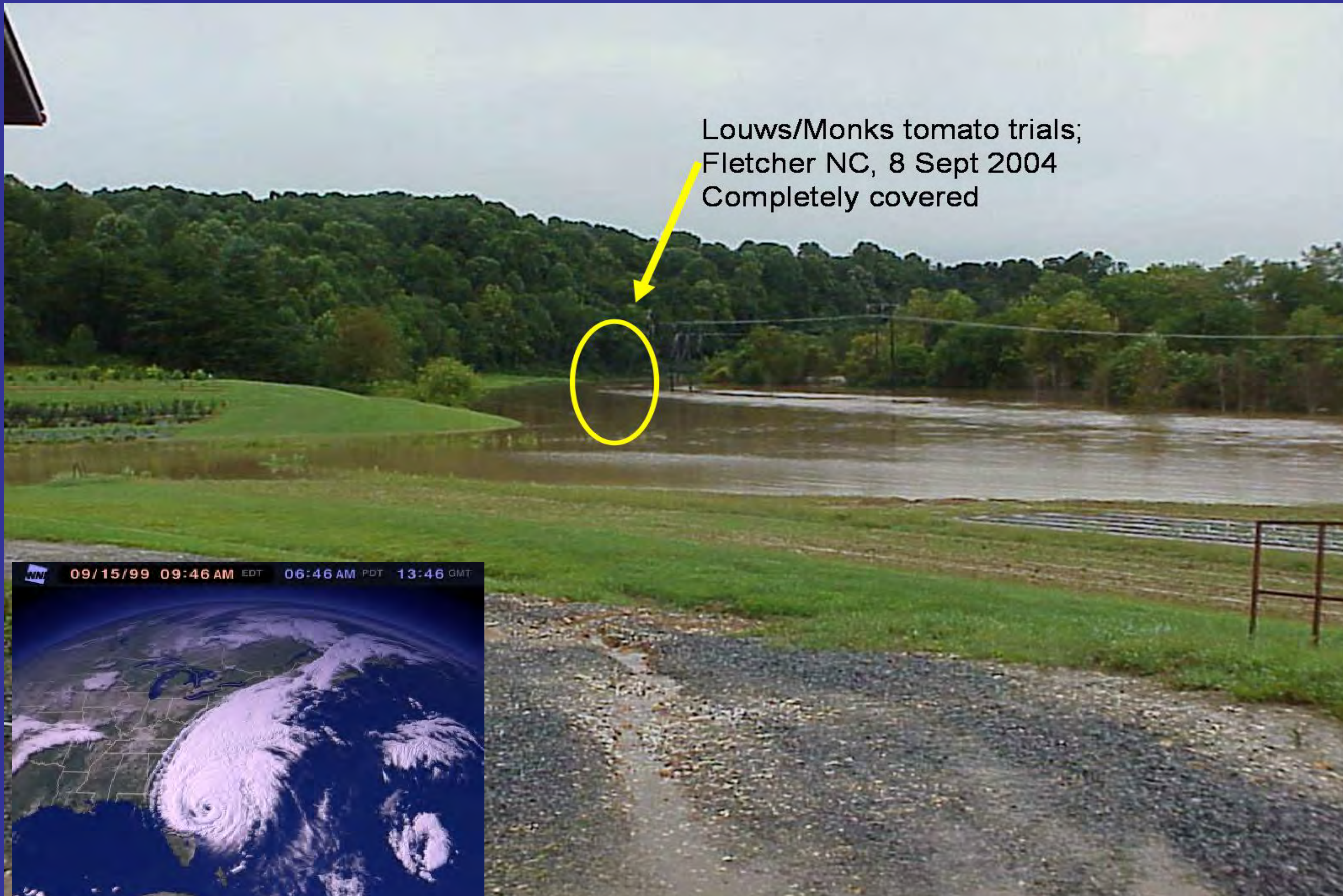
PLANT DISEASE DIAGNOSIS

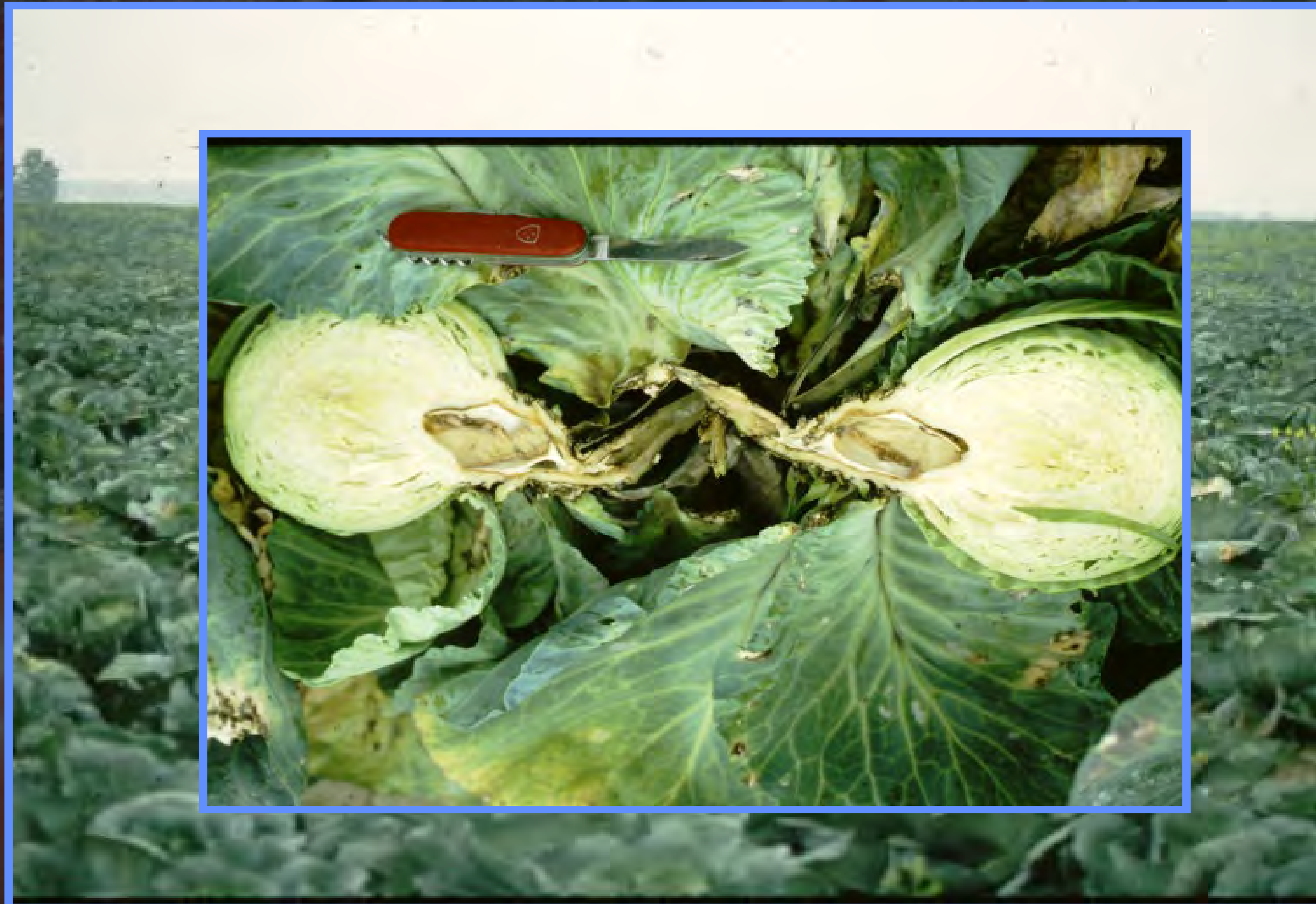
In most cases, routine diagnosis are "preliminary" and diagnose a described disease.

In rare instances, diagnosis is completed to identify an unknown disease – that's a research project!

LEVELS OF RELIABILITY:
Positive Diagnosis (100% reliable)
Accurate Diagnosis (>99% reliable)
Useful Diagnosis (95-99% reliable)
Indicative Diagnosis (85-95% reliable)
Exclusion Diagnosis (100% reliable)

From: M.C. Shurtleff and C.W. Averre III. 1997. The plant disease clinic and field diagnosis of abiotic diseases. APS Press.

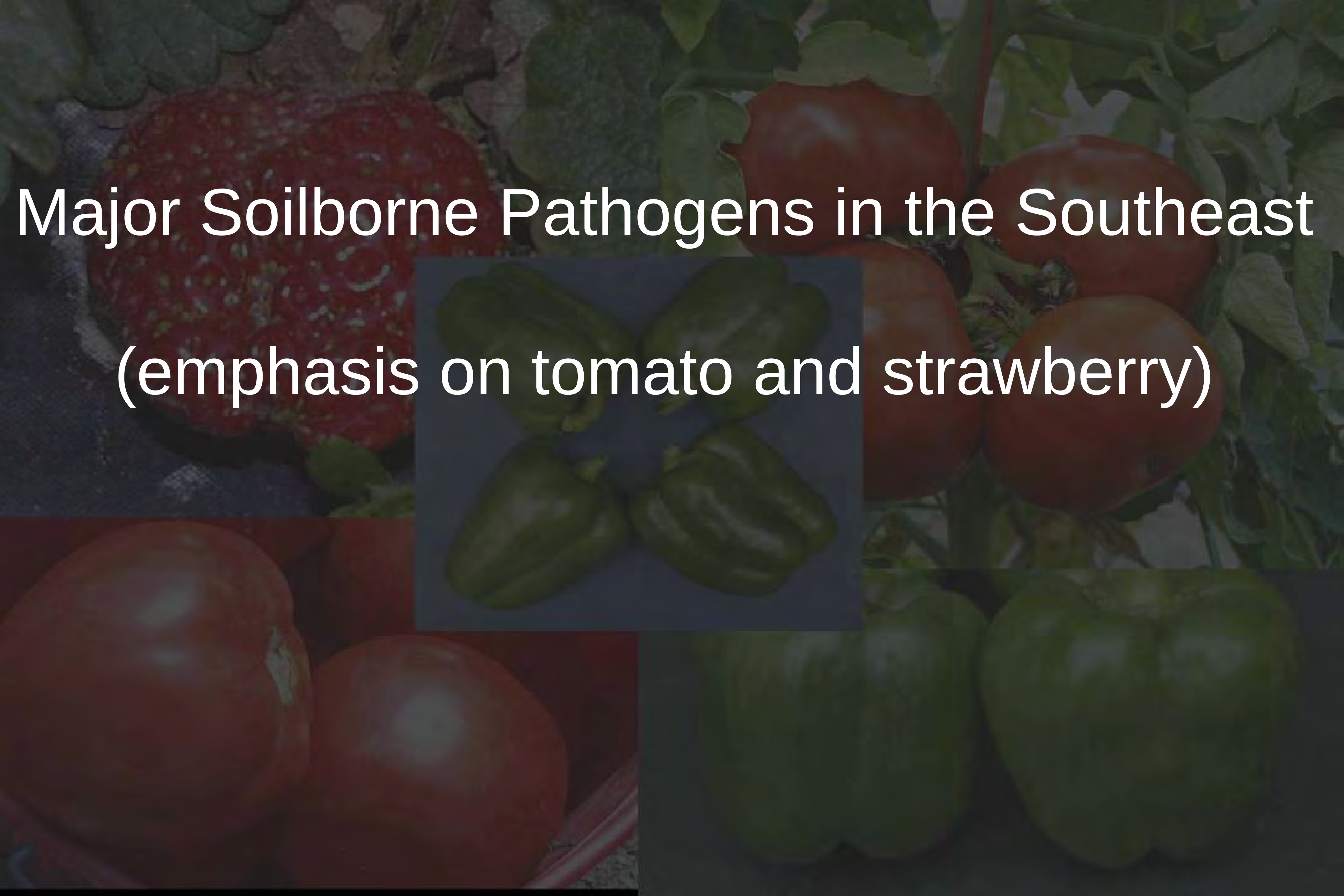

Louws/Monks tomato trials;
Fletcher NC, 8 Sept 2004
Completely covered
09/15/99 09:46 AM EDT 06:46 AM PDT 13:46 GMT




EMERGENCY

Major Soilborne Pathogens in the Southeast

(emphasis on tomato and strawberry)



Four common species of root-knot nematodes (*Meloidogyne* spp.) in the United States:

- **the southern root-knot (*M. incognita*),**
- **the peanut root-knot *(M. arenaria*),**
- **the javanese root-knot (*M. javanica*)**
- **the northern root-knot (*M. hapla*)**

Emerging threat:

- **the guava root-knot (*M. enterolobii*)**

Dissected females out of galls

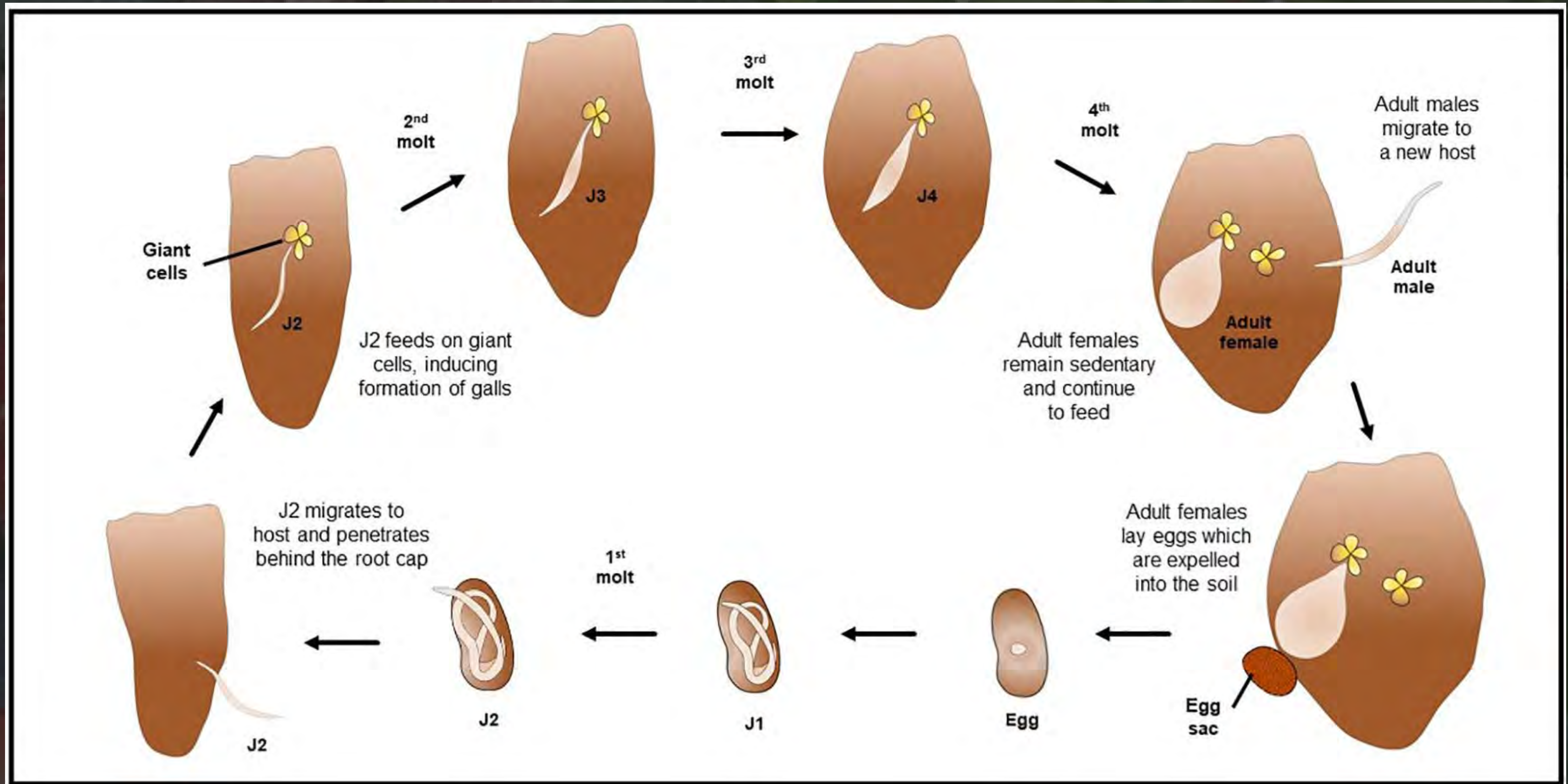


Figure 3. Illustration of the life cycle and root galling of *Meloidogyne enterolobii*.

REVIEW article

Front. Plant Sci., 16 November 2020 | https://doi.org/10.3389/fpls.2020.606395

Meloidogyne enterolobii, a Major Threat to Tomato Production: Current Status and Future Prospects for Its Management

Ashley N. Philbrick[1], Tika B. Adhikari[1*], Frank J. Louws[1,2] and Adrienne M. Gorny[1*]

[1]Department of Entomology and Plant Pathology, North Carolina State University, Raleigh, NC, United States

[2]Department of Horticultural Science, North Carolina State University, Raleigh, NC, United States

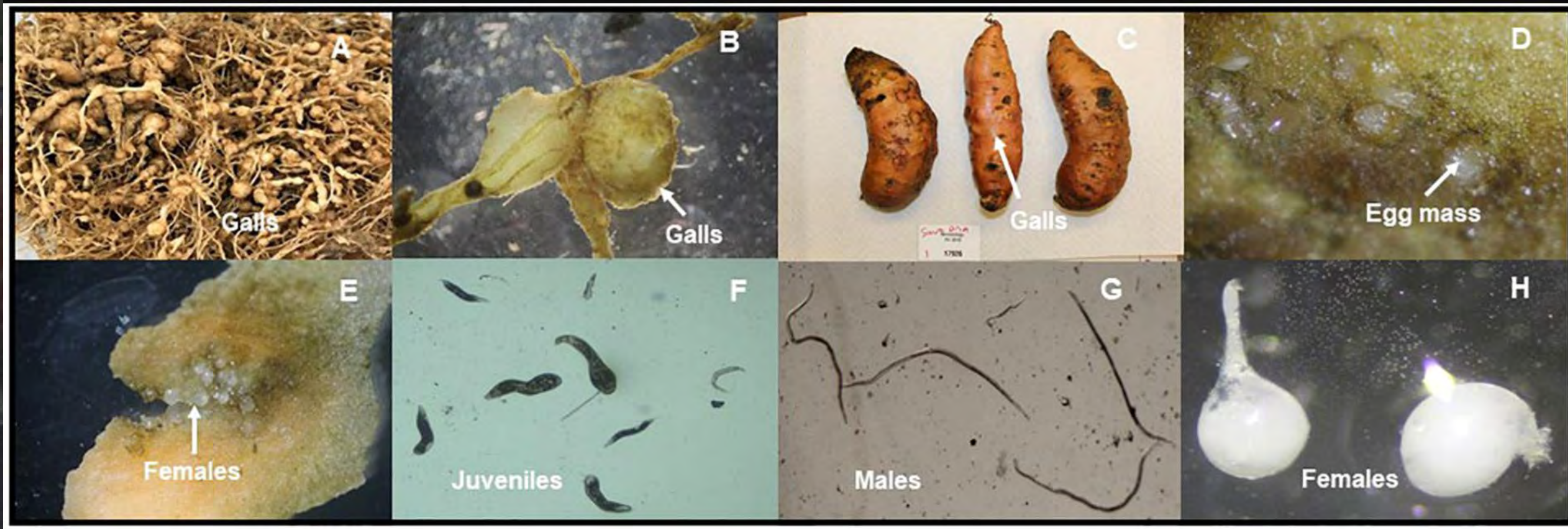


Figure 1. *Meloidogyne enterolobii* individuals and symptoms on different crops in North Carolina, United States (Photos provided by Dr. W. Ye). Large galls and massive root swellings of tomato cv. 'Rutger' in the greenhouse. The nematode was originally collected from Greene County in NC **(A)**. Galls on soybean from Johnston County, NC **(B)**. Galls on sweetpotato from Nash County, NC **(C)**. Egg masses on sweetpotato from Nash County, NC **(D)**. Adult females on sweetpotato from Nash County, NC **(E)**. Infective late second-stage juveniles (J2) from soybean in Johnston County, NC **(F)**. Males from soybean from in Wilson County, NC **(G)**. Females from sweetpotato in Johnston County, NC **(H)**.

Obligate parasite (rotation)
Prevention
Host Resistance
Fumigants
Nematicides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[1]Department of Entomology and Plant Pathology, North Carolina State University, Raleigh, NC, United States
[2]Department of Horticultural Science, North Carolina State University, Raleigh, NC, United States

Fusarium oxysporum f. sp. *lycopersici*

- Fusarium Wilt
- Soil Inhabitant

f.sp. = *forma specialis*

(special form; host specific)

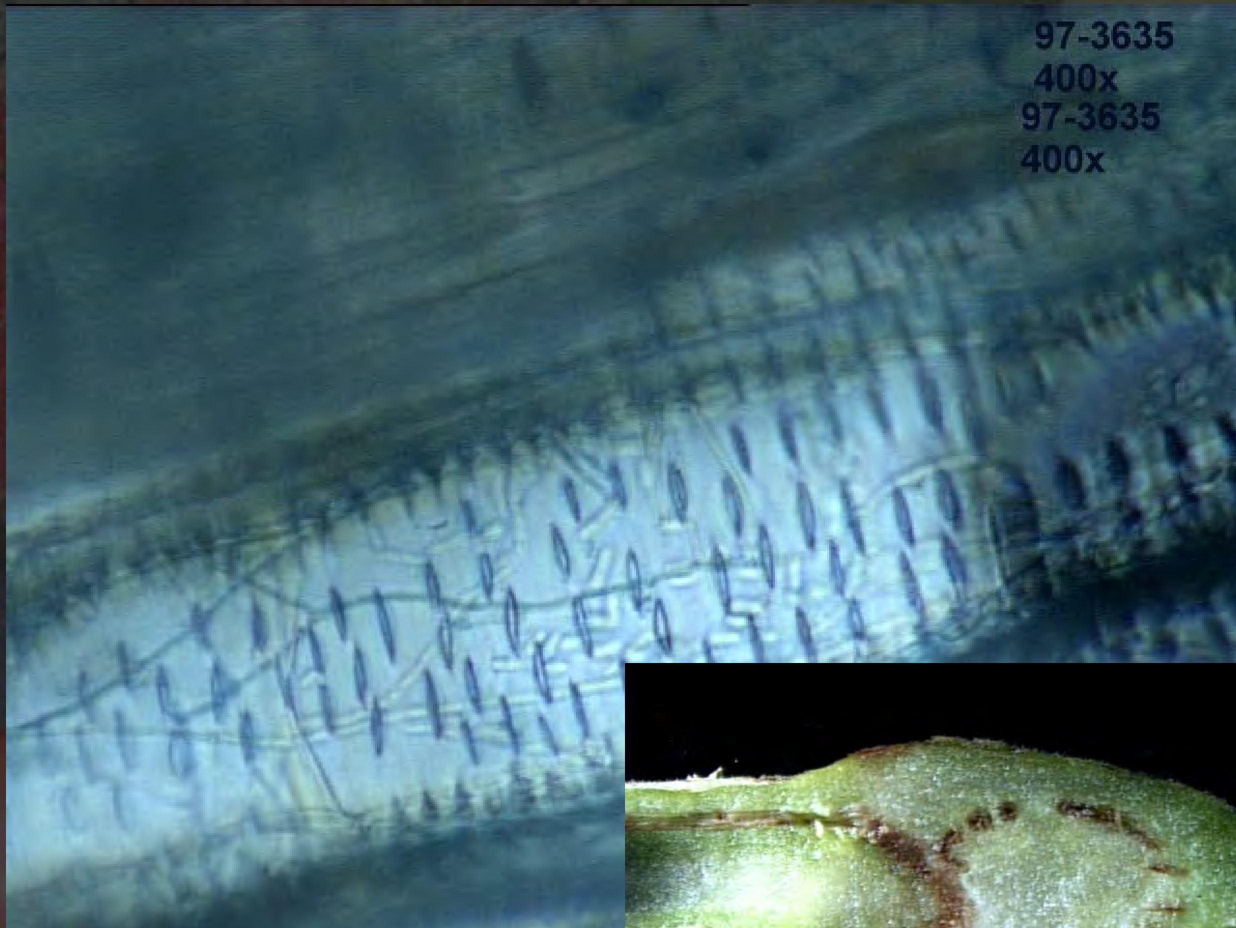
Field

Greenhouse

High-Tunnel

https://peregrinefarm.net/tag/fusarium-wilt/


McKinney, 23,
Hudson Cajah
Mountain Road,
Hickory, arrested
by Lenoir Police
arrest, $5,000
secured bond.
Granite
Falls, arrested
by Caldwell
Harris, 44,
Dogwood Street,
Morganton, arrested
by Caldwell
County Sheriff's
Office, driving while
license revoked,
$3,000 secured bond.
Timothy Dale

97-4082
3.2x tomato l-section

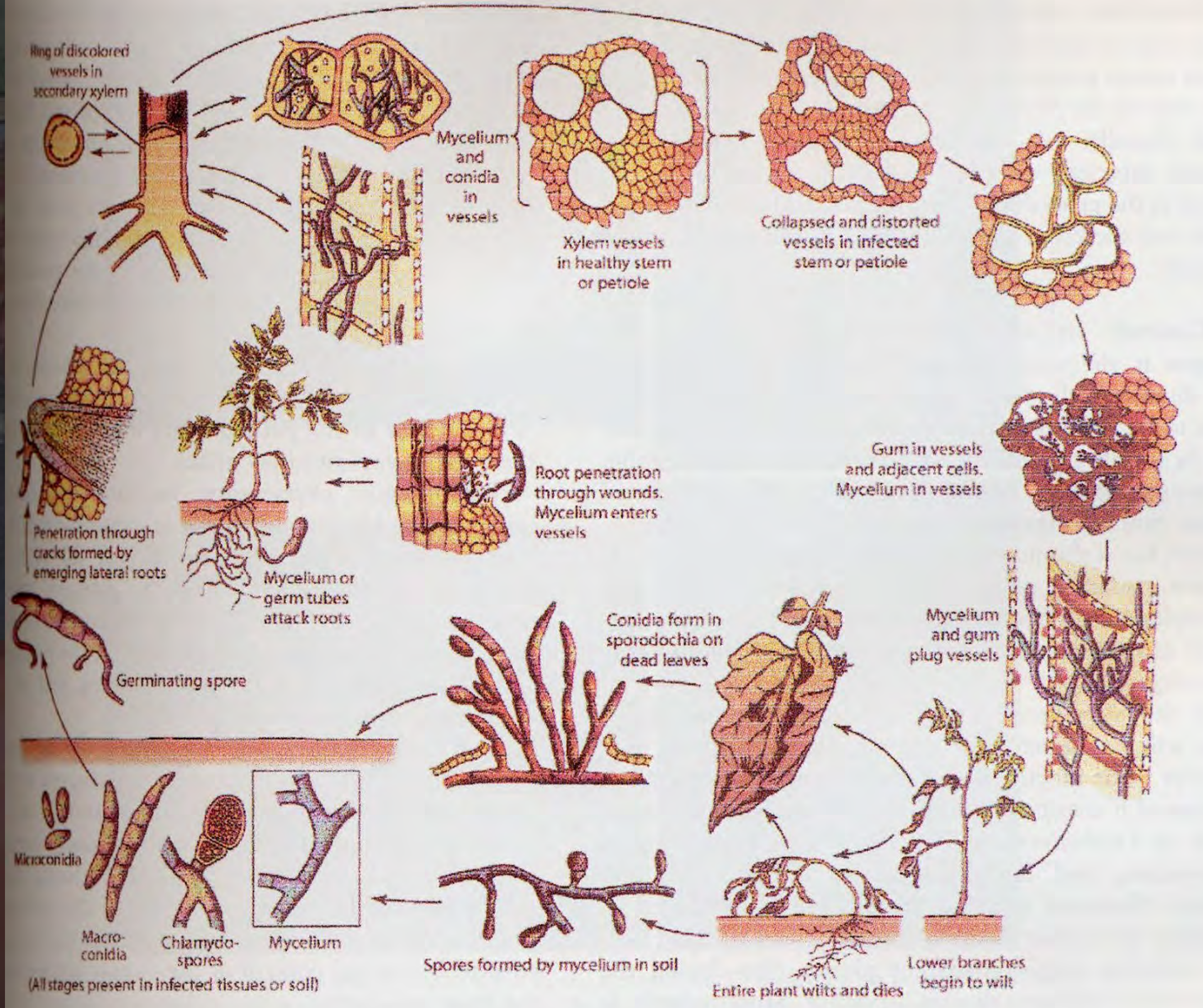


FIGURE 11-105 Disease cycle of *Fusarium* wilt of tomato caused by *Fusarium oxysporum* f. sp. *lycopersici*.

From: G.N. Agrios. 2005. Plant Pathology. 5th edition. Elsevier AP.

Fusarium oxysporum f.sp. *radices-lycopersici*

Fusarium crown and root rot: Introduced on infested plants, contaminated soil or untreated supplies

TOMATO PATHOGEN CODES:

Ff – Leaf mold caused by Fulvia fulva (formerly Cladosporium fulva)
Fol – Fusarium wilt caused by the specified races of Fusarium oxysporum f. sp. lycopersici
For – Fusarium crown and root rot caused by Fusarium oxysporum f. sp. radicis-lycopersici
Lt – Powdery mildew caused by Leveillula taurica
M – Root knot caused by Meloidogyne arenaria, M. incognita and M. javanica
Tm – Mosaic caused by tobamovirus pathotype
ToMV – Mosaic caused by tomato mosaic virus
TMV – Mosaic caused by tobacco mosaic virus
V – Verticillium wilt caused by the specified race of Verticillium albo-atrum, V. dahliae

HR – High resistance
IR – Intermediate resistance

Fusarium oxysporum f.sp. lycopersici
Fusarium wilt

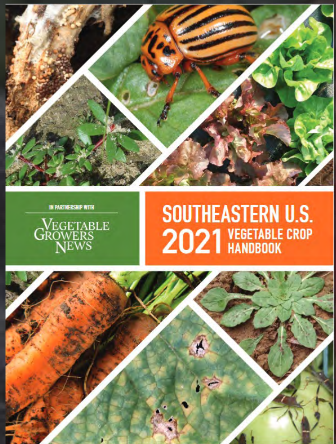
Race 1 (0)
Race 2 (1)
Race 3 (2)

Fusarium: Fol:0,1,2 (EU) = Fol:1,2,3 (US) is same as Fol:0-2 (EU) = Fol:1-3 (US)

Tomato cultivar nomenclature examples:

Big Dena Ff: A-E / Fol: 0-1 (US1-2)/ For / TMV: 0 / ToMV: 0-2 / V (Va: 0, Vd: 0)

Mountain Merit Hybrid Tomato VFFFNTswvEbLb



TOMATOES (*Solanum lycopersicum*)

VARIETIES[1]	AL	AR	GA	KY	LA	MS	NC	OK	SC	TN
TOMATOES										
Fresh Market										
Amelia VR [2, 10, 11, 12, 14, 15, 18]	A	R	G	K	L	M	N		S	T
Bella Rosa [2, 3, 8, 10, 11, 15, 18]	A		G		L	M		O		
BHN 589 [10, 11, 18, 20, 25]	A			K		M				T
BHN 602 [2, 10, 11, 12, 18]	A	R	G	K	L	M	N		S	T
BHN 640 [2, 10, 11, 12, 18]	A	R	G	K	L	M	N		S	T
BHN 669 [4]	A		G			M			S	T
Big Beef [8, 10, 11, 14, 15, 18, 20]		R		K	L	M		O		
Carolina Gold [10, 11, 17, 18]	A	R	G	K	L	M	N	O	S	T
Celebrity [10, 11, 14, 18, 25]	A	R		K	L	M	N	O		T
Crista [2, 10, 11, 12, 14, 16]	A	R	G	K	L	M	N		S	T
Defiant PhR [10,11,18,19,24]	A	R					N		S	T
Emmylou [2, 10, 11, 21]										T
Florida 47R [8, 10, 11, 15, 18]	A	R	G	K	L	M	N	O	S	T
Florida 91 [3, 8, 10, 11, 15, 18]					L	M		O		T
Jolene [10, 11, 18]	A						N			T
Mountain Gem [2, 10, 11, 18, 21, 24, 25]	A						N			T
Mountain Glory [2, 10, 11, 18]	A	R		K			N	O		T
Mountain Magic [9, 10, 11, 18, 19, 24]	A	R	G	K	L	M	N		S	T
Mountain Majesty [2,10,11,18,25]	A		G				N		S	T
Mountain Merit [2, 9, 10, 11, 14, 18, 24]	A									
Mountain Rouge [14, 24]	A				L	M	N		S	
Mountain Spring [10, 11, 15, 18, 25]	A	R	G	K	L	M	N		S	T

[1] Abbreviations for state where recommended.
[2] Tomato Spotted Wilt Virus resistance (TSWV).
[3] Heat set (heat tolerance).
[4] Bacterial wilt resistance.
[7] Determinant or short internode grape tomato.
[8] Alternaria Stem Canker tolerance/resistance (ASC).
[9, 10, 11, 12] Fusarium Wilt race 0, 1, 2, 3 tolerance/resistance (F).
[13] Fusarium Crown Root Rot tolerance/resistance (FCRR).
[14] Nematode resistance (N).
[15] Gray Leaf Spot resistance (St).
[16] Tobacco Mosaic Virus resistance (TMV).
[17] Yellow fruit.
[18] Verticillium Wilt resistance (V).
[19] Early Blight tolerance/resistance.
[20] Tomato Mosaic Virus resistance (ToMV).
[21] Tomato Yellow Leaf Curl Virus resistance (TYLCV).
[22] Orange fruit.
[23] Salad size (Campari type).
[24] Late blight tolerance/resistance.
[25] Suitable for high tunnel production.
[26a-e] Tomato leaf mold race A,B,C,D,E tolerance/resistance.
[27] Powdery mildew tolerance/resistance.
[28] Bacterial speck tolerance/resistance (BSK-0).

Differential hosts

F1,2,3

F1,2

F1

F-

Universal suscept

FIGURE 2 Disease phenotypes caused by *Fusarium oxysporum* f. sp. *lycopersici* on four tomato cultivars 21 days after inoculation in the greenhouse. Tomato differential cultivars inoculated with race 1 isolate Fu 5 **(A)**, and tomato differential cultivars inoculated with race 3 isolate Fu 24 **(B)**.

Front Microbiol. 2020 Aug 27;11:1995. doi: 10.3389/fmicb.2020.01995. eCollection 2020.

Pathogenomics Characterization of an Emerging Fungal Pathogen, *Fusarium oxysporum* f. sp. *lycopersici* in Greenhouse Tomato Production Systems

Tika B Adhikari [1], Anne Gao [2], Thomas Ingram [1], Frank J Louws [1 3]

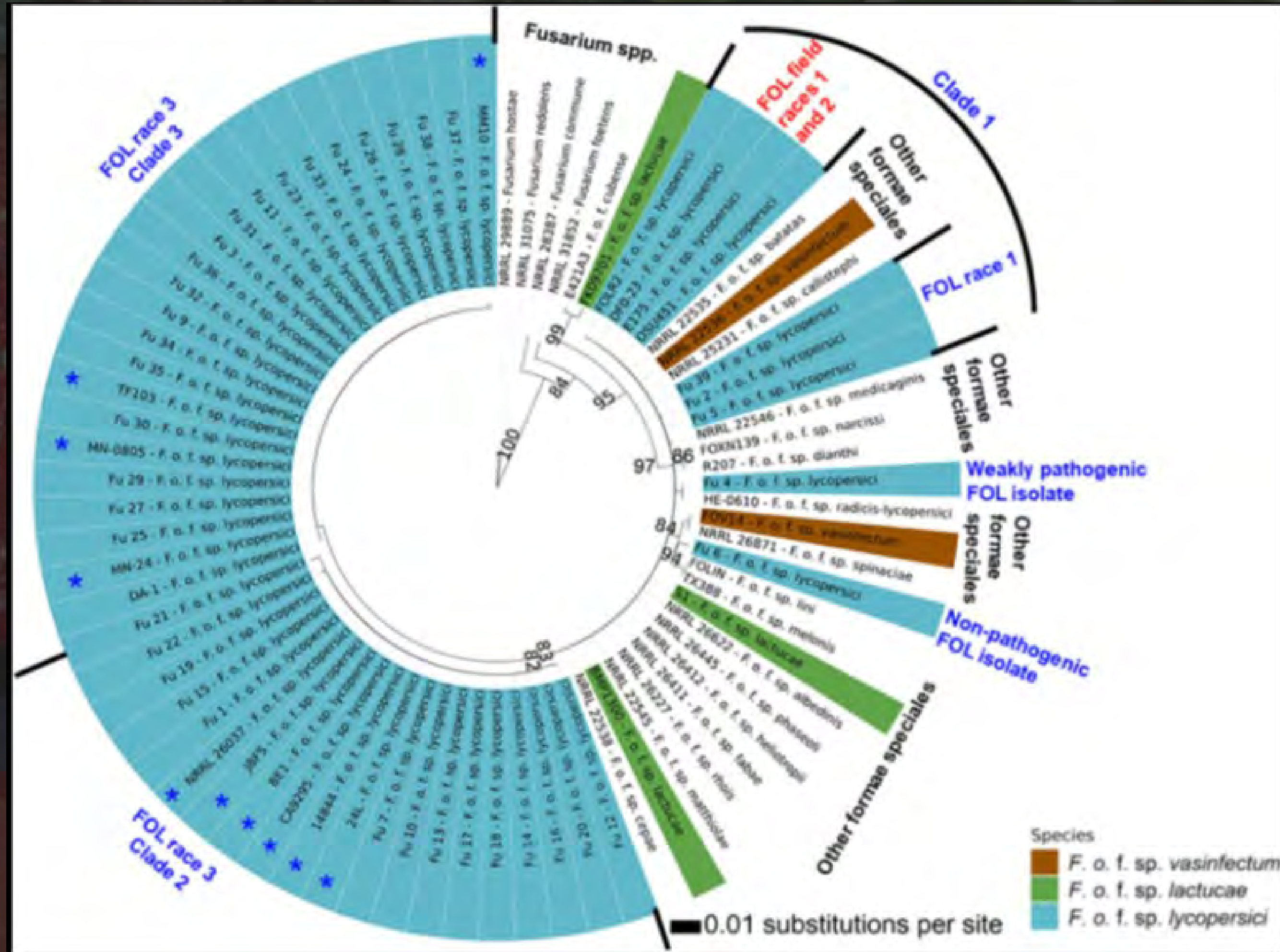


FIGURE 7 The Maximum-likelihood phylogenetic trees of the 38 isolates of *Fusarium oxysporum* f. sp. *lycopersici* (FOL) sampled from tomato in the greenhouses in North Carolina generated from the translation elongation factor 1-α encoding gene *tef1- α* sequences.

> Front Microbiol. 2020 Aug 27;11:1995. doi: 10.3389/fmicb.2020.01995. eCollection 2020.

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Verticillium Wilt

- ***Verticillium dahliae* (race 1 & 2)**
  - Loss of vigor
  - Wilting and leaf necrosis
  - Favored in temperate climates
  - "Race 2" prevalent in WNC (*Bender & Shoemaker, 1984*)
  - Highly persistent in soils
  - Non-host specific

Susceptible and “tolerant” tomato lines NC Vd (probably race 3)

Lines developed by Randy Gardner; Picture: F. J. Louws; 2019

FIGURE 1 Phylogenetic tree developed from whole genome alignment of *V. dahliae* isolates from multiple hosts, countries, and mating types.

FIGURE 6 Protein sequence alignment of the R2C1 *VdPDA1* gene. Sequences highlighted in black (21–26) have not been tested for the race2/3 phenotype. A single nucleotide polymorphism of A to T results in an isoleucine (ATC) to phenylalanine (TTC) conversion.

The majority of strains in NC are Race 3

> Front Microbiol. 2020 Nov 30;11:573755. doi: 10.3389/fmicb.2020.573755. eCollection 2020.

Comparative Genome Analyses of 18 *Verticillium dahliae* Tomato Isolates Reveals Phylogenetic and Race Specific Signatures

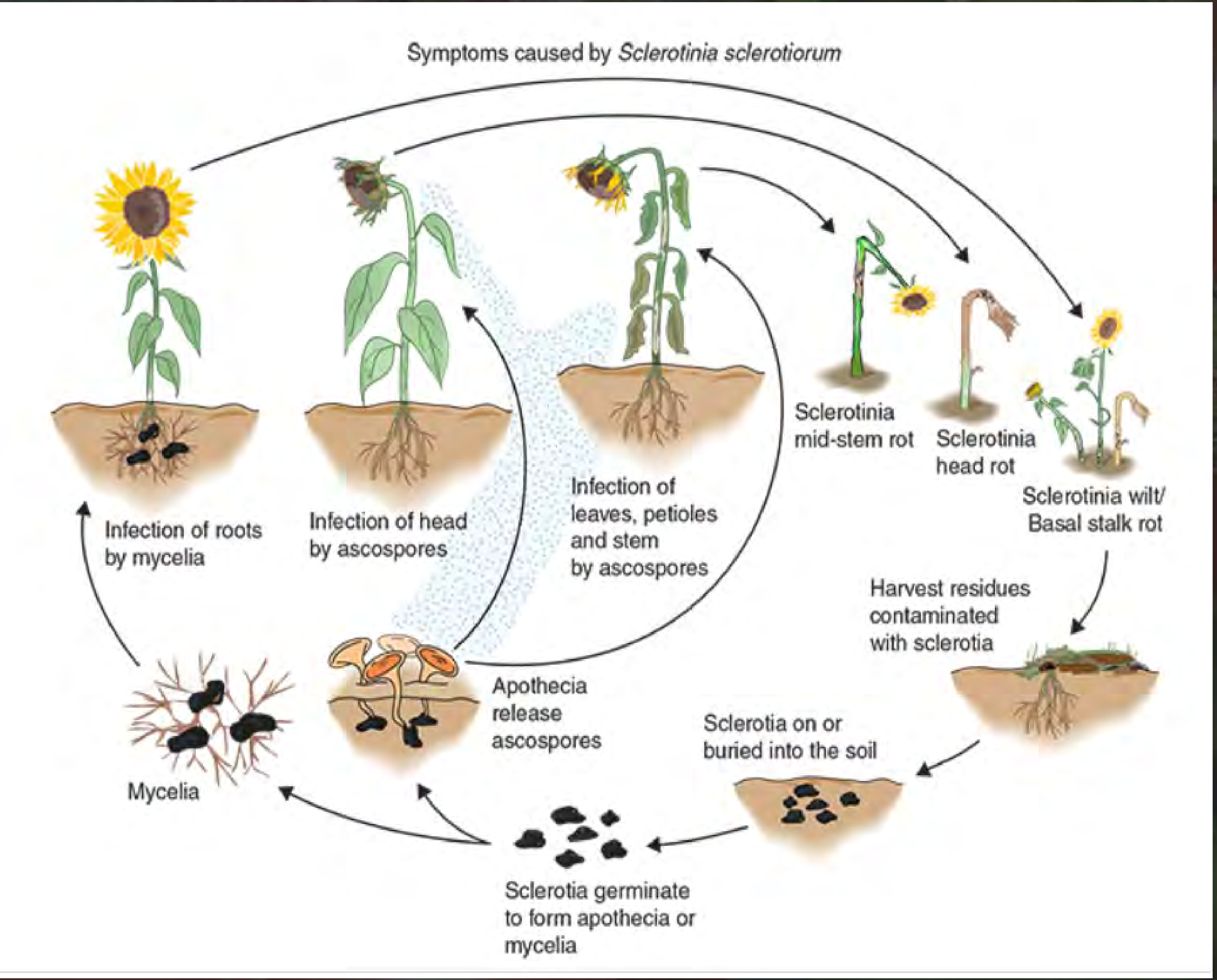
Thomas W Ingram [1], Yeonyee Oh [1], Tika B Adhikari [1], Frank J Louws [1 2], Ralph A Dean [1]

Southern Stem Blight

- ***Sclerotium rolfssi***
  - – Basal lesions at soil line
  - – Wilting and sudden plant death
  - – Favored in sub- to tropical climates
  - – Widely distributed in the South
  - - Highly persistent in soils
  - - Non-host specific
  - - Wide host range
  - - Produces sclerotia

White Mold; Timber Rot

- ***Sclerotinia sclerotiorum***
  - Can affect multiple plant parts
  - Favored by coller temperatures
  - Produces black sclerotia
  - Highly persistent in soils
  - Non-host specific
  - Wide host range



More common in greenhouses

Mathew, F., Harveson, R., Block, C., Gulya, T., Ryley, M., Thompson, S., and Markell, S. 2020. Sclerotinia sclerotiorum Diseases of Sunflower (White mold). Plant Health Instructor.

https://www.apsnet.org/edcenter/disandpath/fungalasco/pdlessons/Pages/SclerotiniaSunflower.aspx

- *Ralstonia solanacearum*
  - Southern Bacterial Wilt
  - Colonizes Vascular tissue
  - Tropical Environments
  - Soil Inhabitant
  - Wide host range

Riley, M.B., M.R. Williamson, and O. Maloy. 2002.
Plant disease diagnosis. *The Plant Health Instructor*. DOI: 10.1094/PHI-I-2002-1021-01
Plant Disease Diagnosis

Pith Necrosis (Sporadic)

Pseudomonas corrugata

Avoid excess N

Rotate

Figure 1. Symptoms of pith necrosis:

A. Four-week-old "Mountain Pride" tomato plants. Note stunting of the diseased plant.

B. Internal appearance of the main stem of the diseased plant shown in (A). Note discoloration, hollowing, and adventitious root initials in the pith.

C. Pith necrosis in a ten-week-old "Mountain Delight" tomato plant. Note browning of the stem and collapse of several leaf petioles. Even with severe pith necrosis, this plant is still bearing fruit.

D. Internal appearance of the main stem of the diseased plant shown in (C). Note dark brown discoloration and disking in the pith.

E. Severe pith necrosis. Note adventitious roots in affected area.

Prepare soil and apply plastic (15 Aug – 15 Sep)

Plant 15 Sep – 15 Oct

Manage Oct - Mar

Harvest Apr – Jun (20-30K lb/A)
And start over….

WHO IS THE ENEMY? (WHY DO WE FUMIGATE?)

Black Root Rot Complex

Chandler
San Andreas

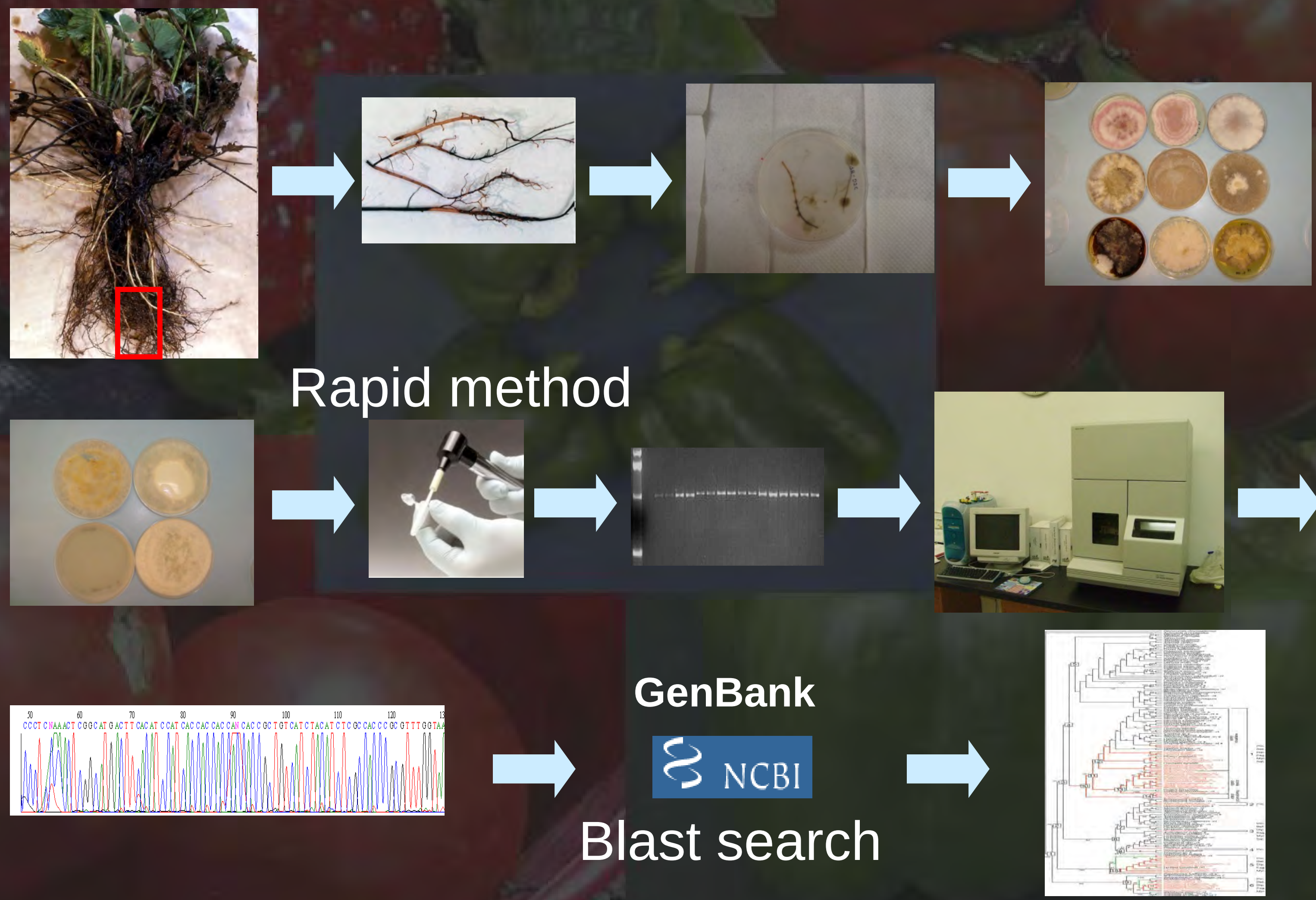
Benecia

Benecia
(outside row)
Low disease

Benecia
High disease
pressure

Benecia roots showing poor root structure; BRR symptoms and “Rat-Tail” appearance

Fungal detection and identification using selective media



Who is the enemy?

- *Isolated and characterized over 1300 fungi using a hierarchical sampling scheme*
    - *Fungal complex varies with crop production site*
    - *Clean plants are difficult to obtain*
- *Rhizoctonia fragariae* : AG-G, AG-A, AG-I
- *Pythium irregulare, Pythium spinosum,*

  Pythium artotrogus, Pythium HS
- *Fusarium solani* and *Fusarium oxysporum*

- Phytophthora crown rot: *Phytophthora cactorum*
- *Phytophthora bisheria* Abad, Abad and Louws sp. nov.
- *Fusarium oxysporum* f.sp. *fragariae*

Table 3: Summary of fungi isolated from strawberry roots showing symptoms of black root rot in various locations across NC.

FUNGI		LOCALITIES				
		Clayton (eastern NC	Fletcher (mountains)	Bunn (piedmont)	Plymouth (eastern NC)	TOTAL
Rhizoctonia 'fragariae'		**5**	**48**	**84**	**85**	**222**
	AGA	0	14	41	53	108
	AGI	0	4	9	10	23
	AGG	0	14	29	12	55
	unknown/other	5	16	5	10	36
Pythium spp.		**203**	**20**	**12**	**128**	**363**
	P. irregulare	201	2	1	78	282
	12 other species/groups	2	18	11	50	81
Fusarium spp.						
	12 different species	20	15	31	88	**154**
OTHERS						
	27 different Genus/species	77	18	57	220	**372**
					TOTAL OF ISOLATES	**1111**

Fungi were isolated from roots using multiple semi-selective media and identified using morphological and molecular methods. Note: These data represent isolations from strawberry roots over multiple sites and years; each site may have been sampled more than once over 2 to 3 years. Data reflects successful isolations from a hierarchical sampling scheme; not proportional data. Therefore these data do not reflect direct comparisons across sites but show predominance of specific profiles within each sample site. Summarized work by Z.G. Abad and F.J. Louws.

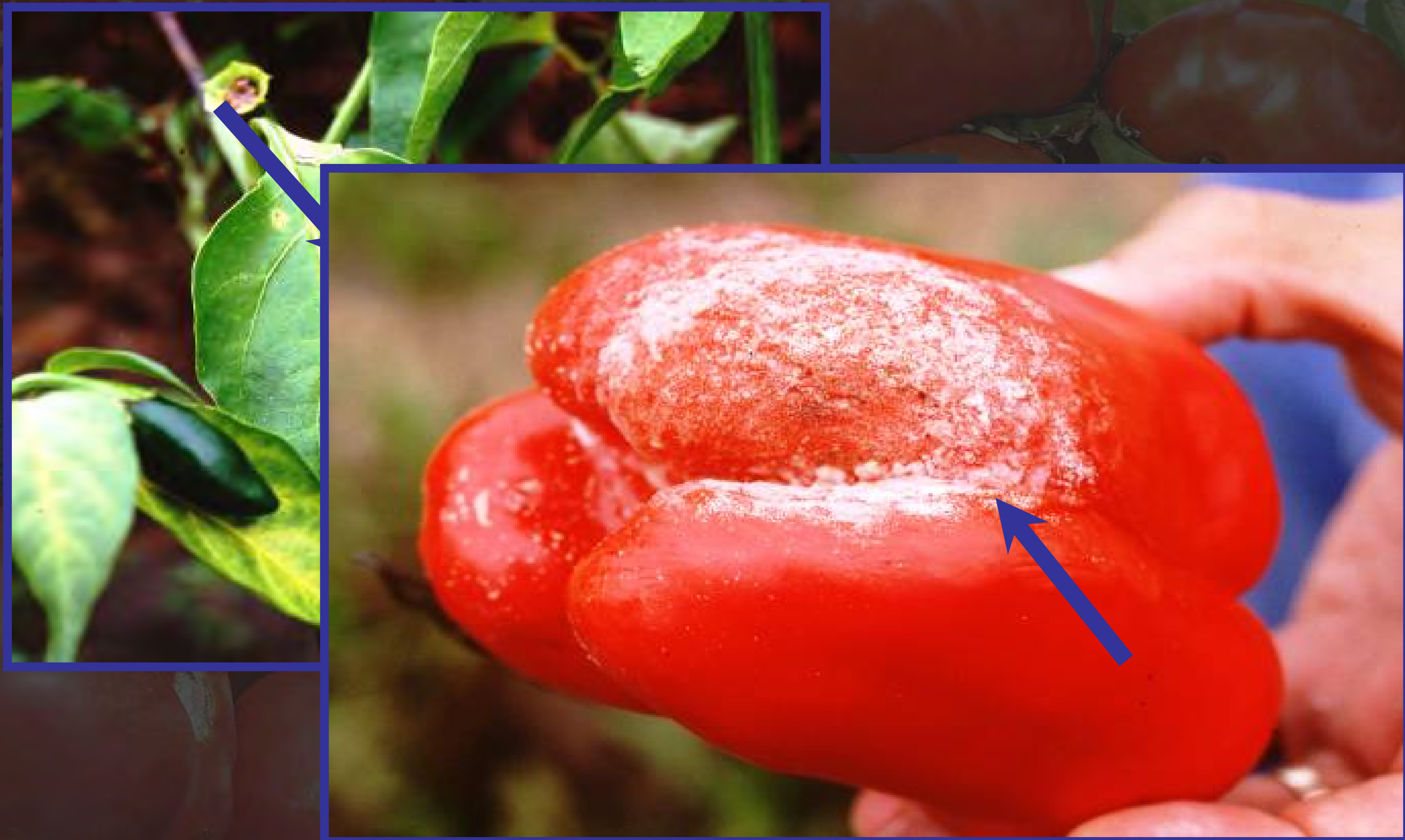
The Oomycetes: Pythium and Phytophthora

Pythium damping off of tomato roots

PEPPER ROOT AND CROWN ROT

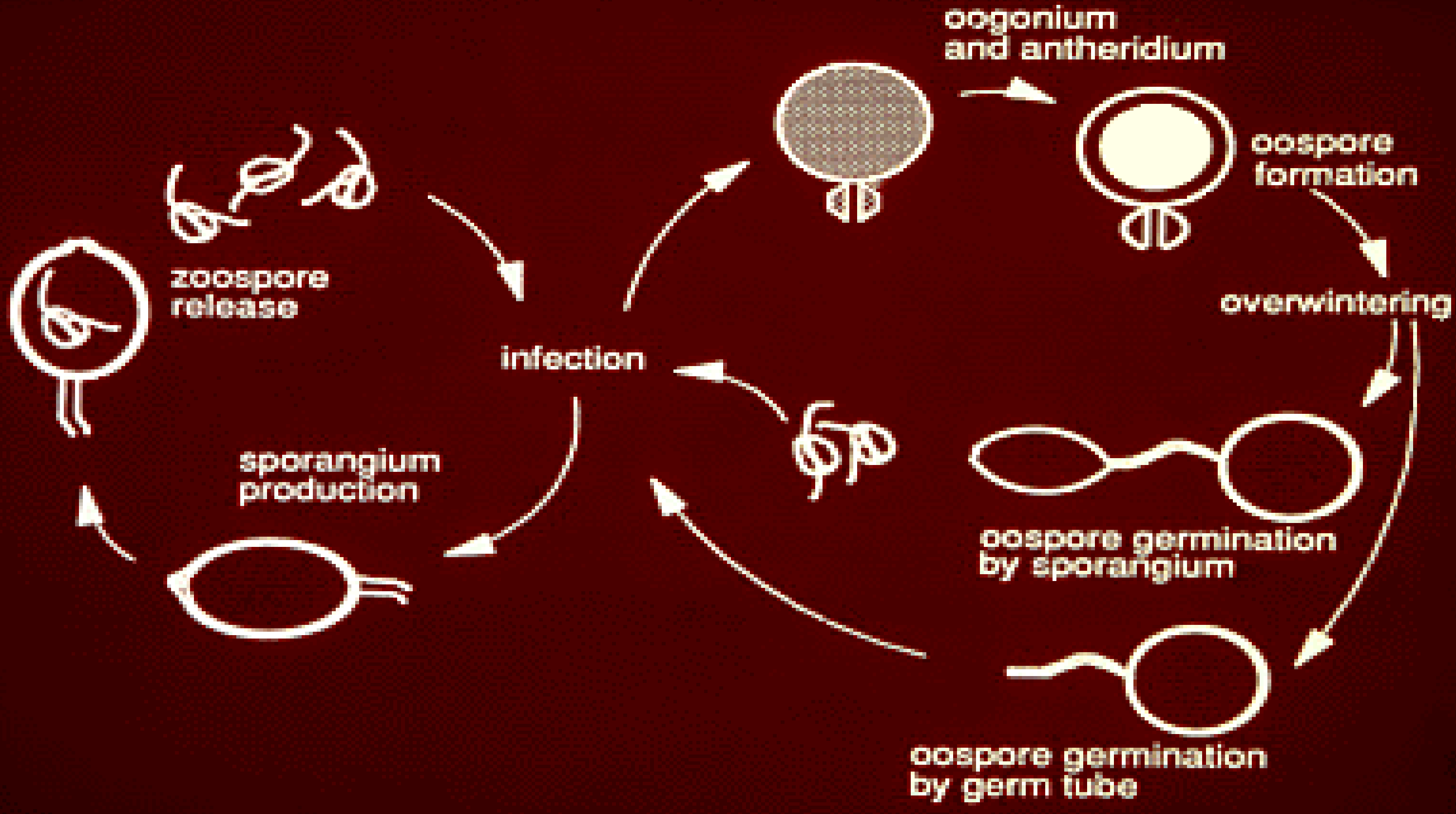
SYMPTOMS: PROCESSING/FRESH

SYMPTOMS: FOLIAR BLIGHT/FRUIT ROT



Phytophthora Symptoms on Squash

Life Cycle of *Phytophthora capsici*

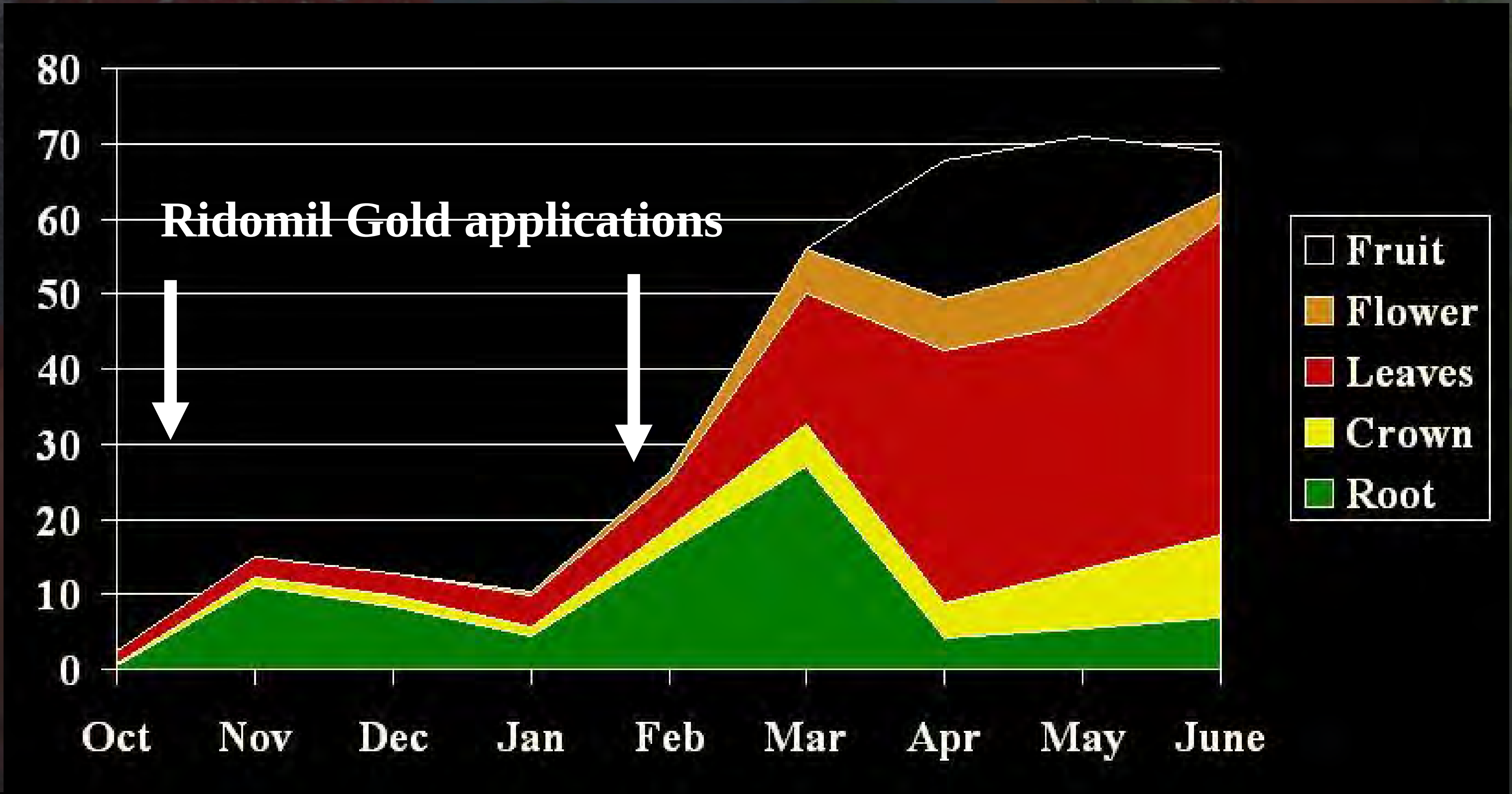


Oospores of *P. cactorum* can be seen in infected strawberry root tissue

(Photo courtesy of F.J. Louws, NC State University)

Phytophthora crown and root rot

Root-development phenology-based recommendations



The IPM PYRAMID

Fungicides (Fumigants)

Biological control

Sanitation

Cultural control

Environmental control

Genetic resistance

Crop Selection

Growing system

Site Selection

Grower Knowledge/Experience

Importance and relative efficacy of IPM tactics and Current use of host resistance to manage major pathogens of tomato and strawberry

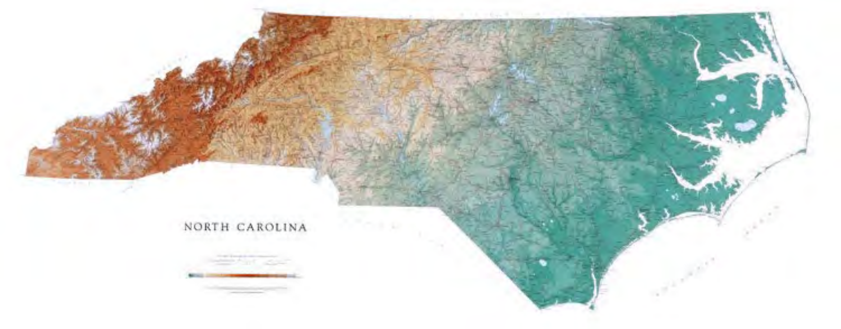
Soilborne Pathogen of Importance in the SEUS	Seriousness of the Disease	Crop Rotation	Fumigant Soil Disinfestation	Other IPM tactics	Host Resistance
TOMATO					
Fungi					
Verticillium dahliae race 1	****	*	***	*	****
Verticillium dahliae (other than race 1)	****	*	***	*	NA
Fusarium oxysporum f.sp. lycopersici (race 1, 2 & 3)	****	*	**	*	****
Fusarium oxysporum f.sp. radicis-lycopersici	***	*	**	*	****
Sclerotium rolfsii	***	*	***	**	ND
Oomycetes					
Phytophthora capsici	*	**	**	**	NA
Pythium sp.	*	***	****	**	NA
Bacteria					
Ralstonia solanacearum	****	*	*	**	***
Nematodes					
Root knot	****	***	****	***	****

Importance and relative efficacy of IPM tactics and Current use of host resistance to manage major pathogens of tomato and strawberry

Soilborne Pathogen of Importance in the SEUS	Seriousness of the Disease	Crop Rotation	Fumigant Soil Disinfestation	Other IPM tactics	Host Resistance
STRAWBERRY					
Fungi					
Rhizoctonia fragariae	****	*	***	*	NA
Fusarium sp. (not wilt)	*	***	****	*	NA
Sclerotium rolfsii	***	*	***	**	NA
Oomycetes					
Phytophthora cactorum	***	**	**	**	*
Pythium irregulare	****	***	****	**	NA
Nematodes					
Root knot	****	***	****	***	ND

Regional importance of various soilborne tomato pathogens in North Carolina

Pathogen	ECOLOGICAL ZONE			Graft Potential
	Coastal Plain	Piedmont	Mountains	
Verticillium dahliae race 1	----	*	***	****
Verticillium dahliae race 2	----	*	****	**
Fus. oxy. f.sp. *lycopersici race 0 or 1*	****	****	****	****
Fus. oxy. f.sp. *lycopersici race 2*	*	**	****	**
Ralstonia solanacearum (race 1)	****	***	*	****
Sclerotium rolfsii	****	**	----	***
Phytophthora capsici	***	***	***	*
Meloidogyne incognita	****	**	*	****



Louws et al. 2010

Challenges with Managing Soilborne Diseases

- Microscopic: difficult to sample and monitor; (scouting)
- Patchy distribution
- Persistent and “responsive” inoculum (thresholds)
- Complex of pathogens that act together
- Generally requires prophylactic control – not reactive

Practice

Science

Generation 4 – SUSTAINABLE SYSTEMS

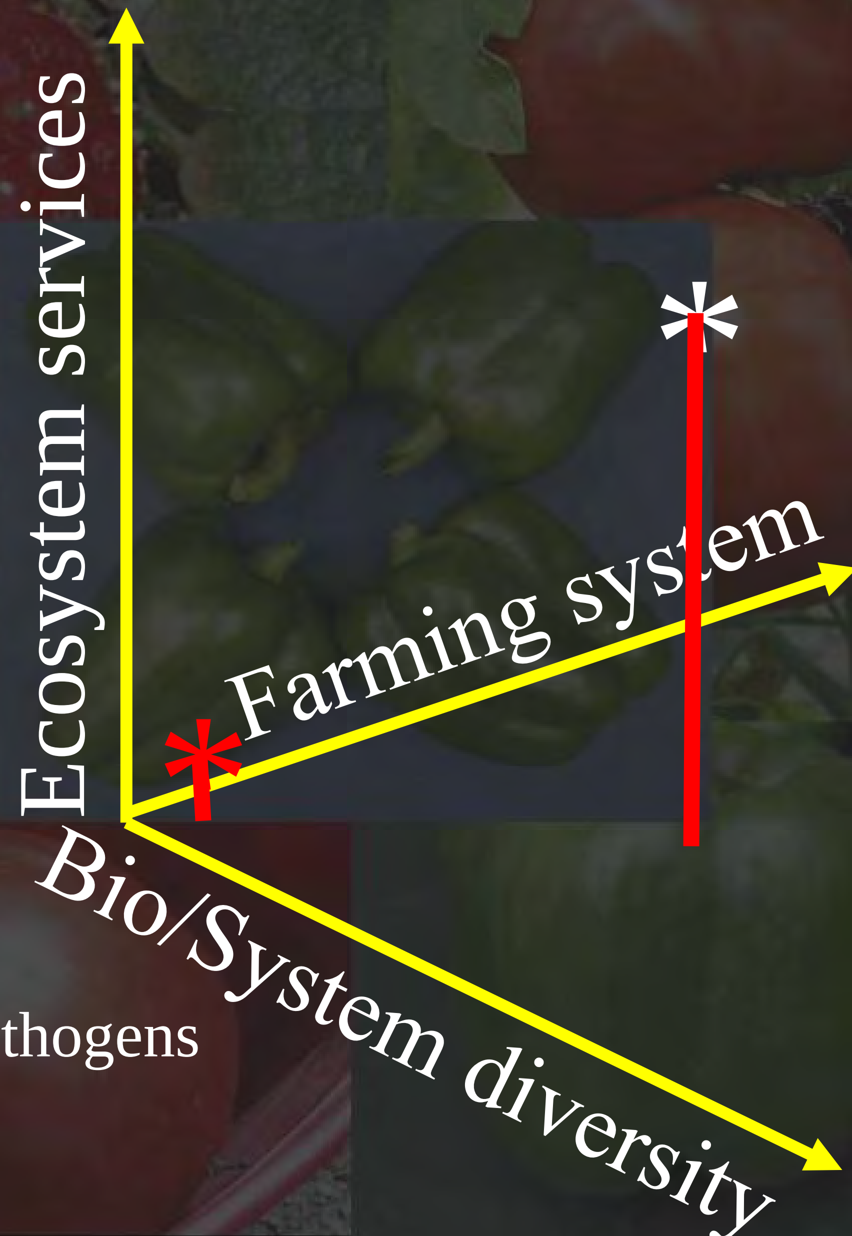
Can you design Farming Systems that have suppressive soils and promote plant health? (multi-functional)

Descriptive

Prescriptive

Multifunctional production systems

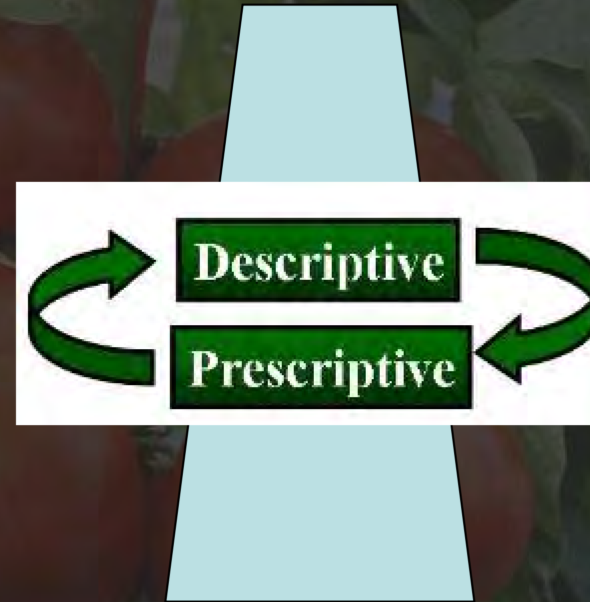
- Disease suppression
- Plant growth promotion
- Good Yields
- Weed suppression
- Nutrient cycling/CEC



- •Cover crops
- •Compost
- •Crop rotation
- •Nutrient mgmt
- •Multi-crop management
- •Expanded knowledge/mgmt needs

- •Biologicals
- •Knowledge of pathogens
- •Soil community
- •Crop diversity

ADVANCING THE FRONTIER OF SUSTAINABLE AG



A + B = X

{ A C D E F B } X

Input based

Tactic substitution

Process based

Tactic development