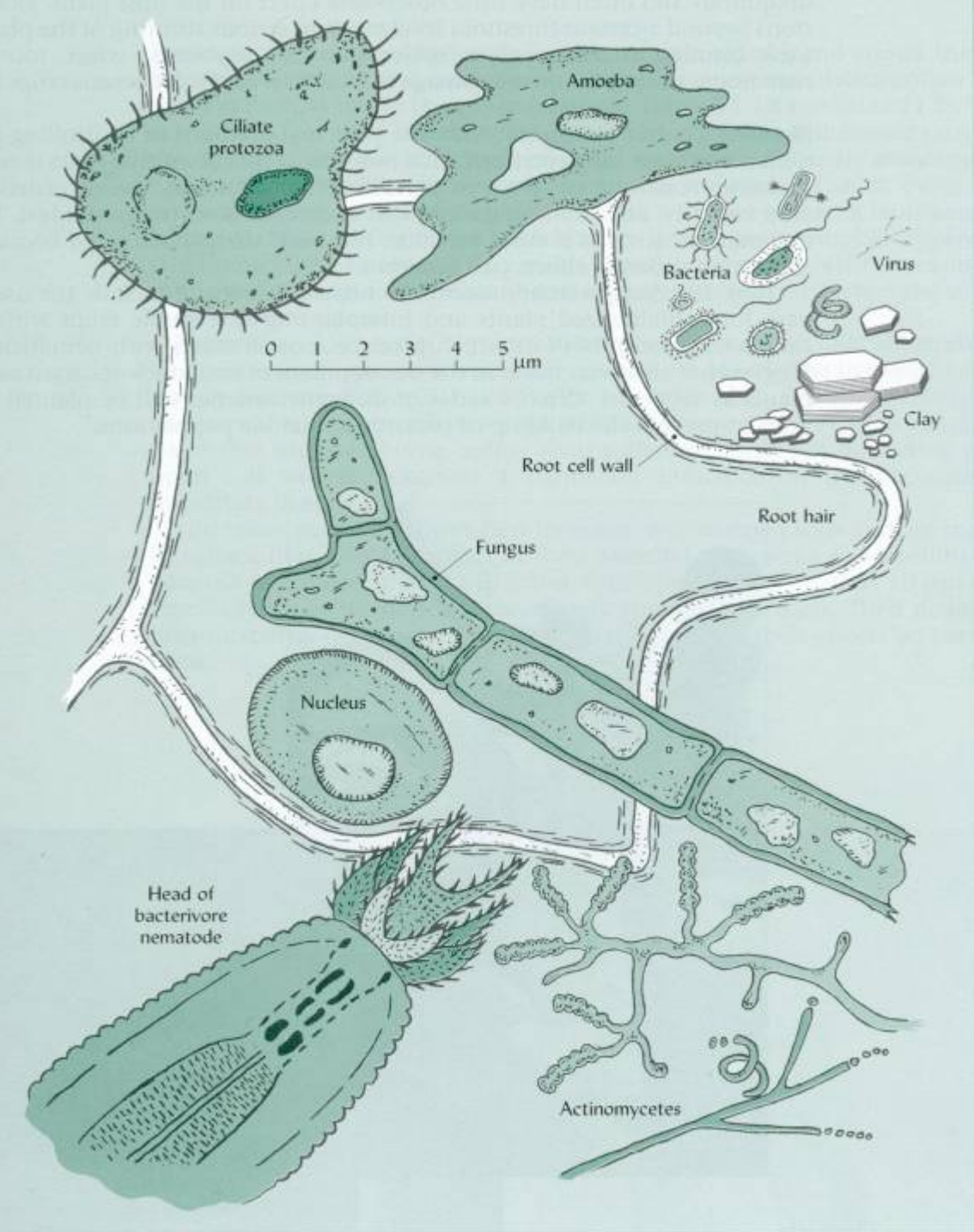
An Introduction to Soil Ecology

November 8, 2004

Allison Hornor

Most images in slides from:

Dr. Janice Thies

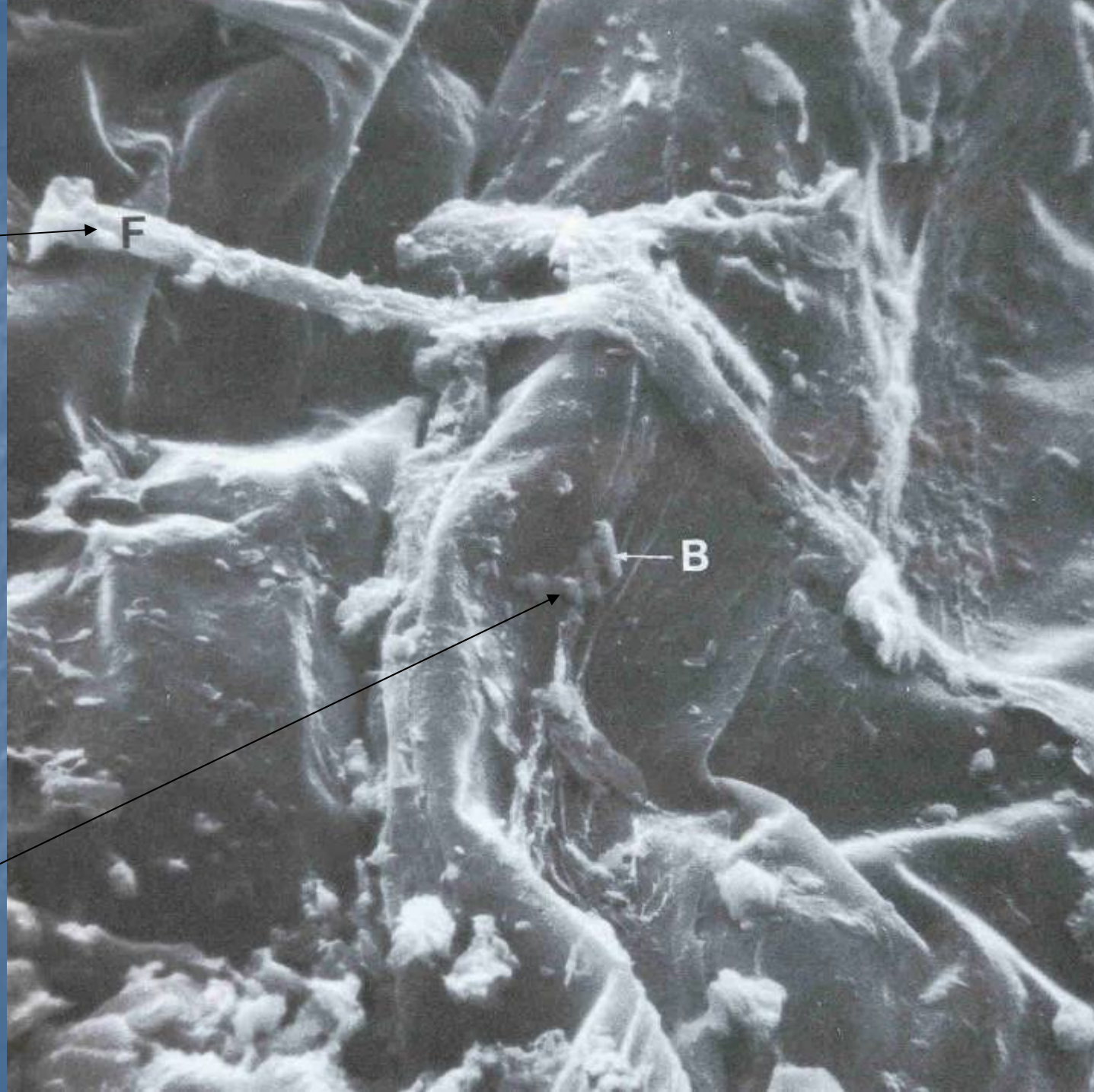


Relative size of soil organisms

Fungal hyphae

Microbes on a root surface

Bacteria



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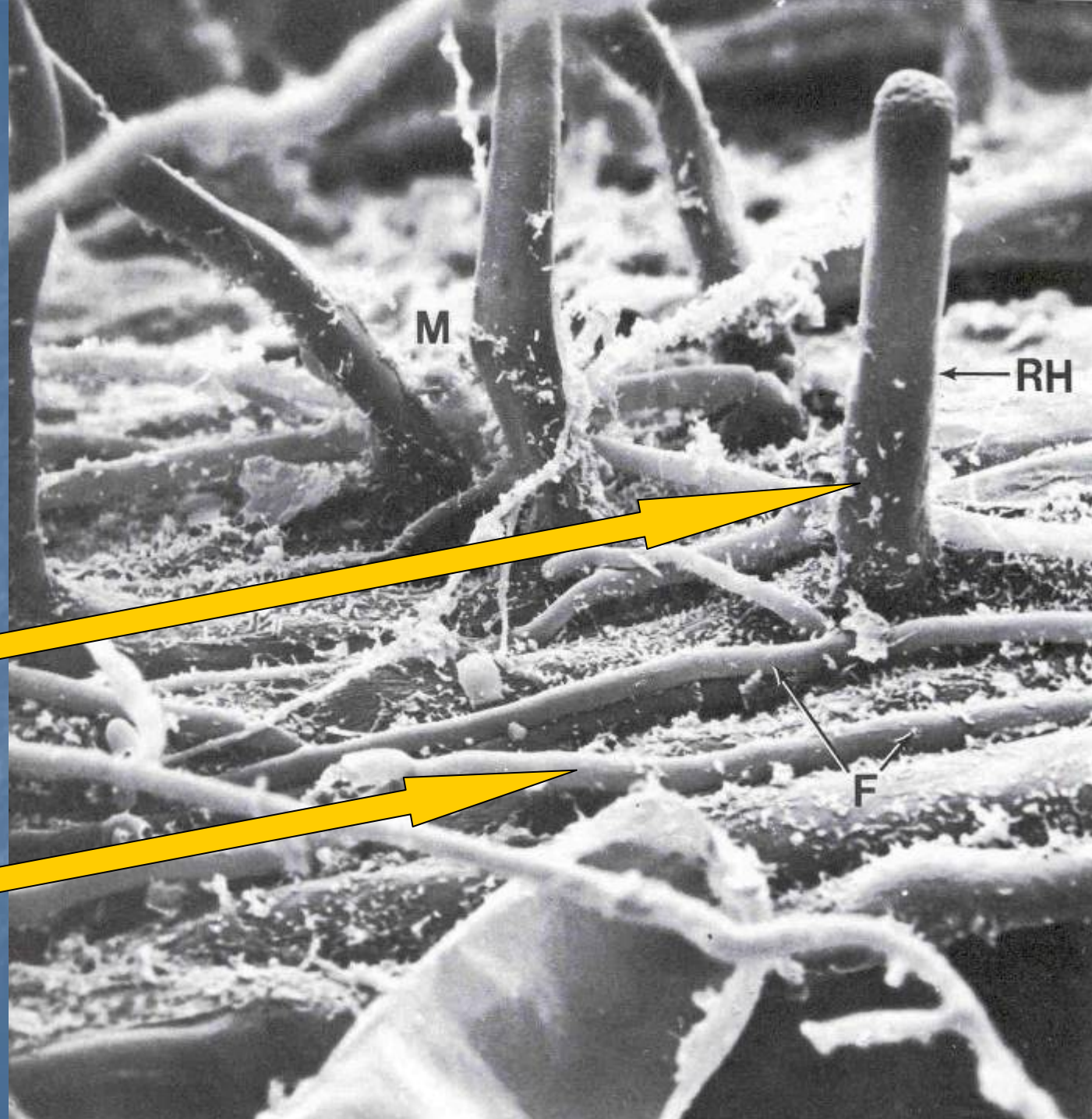
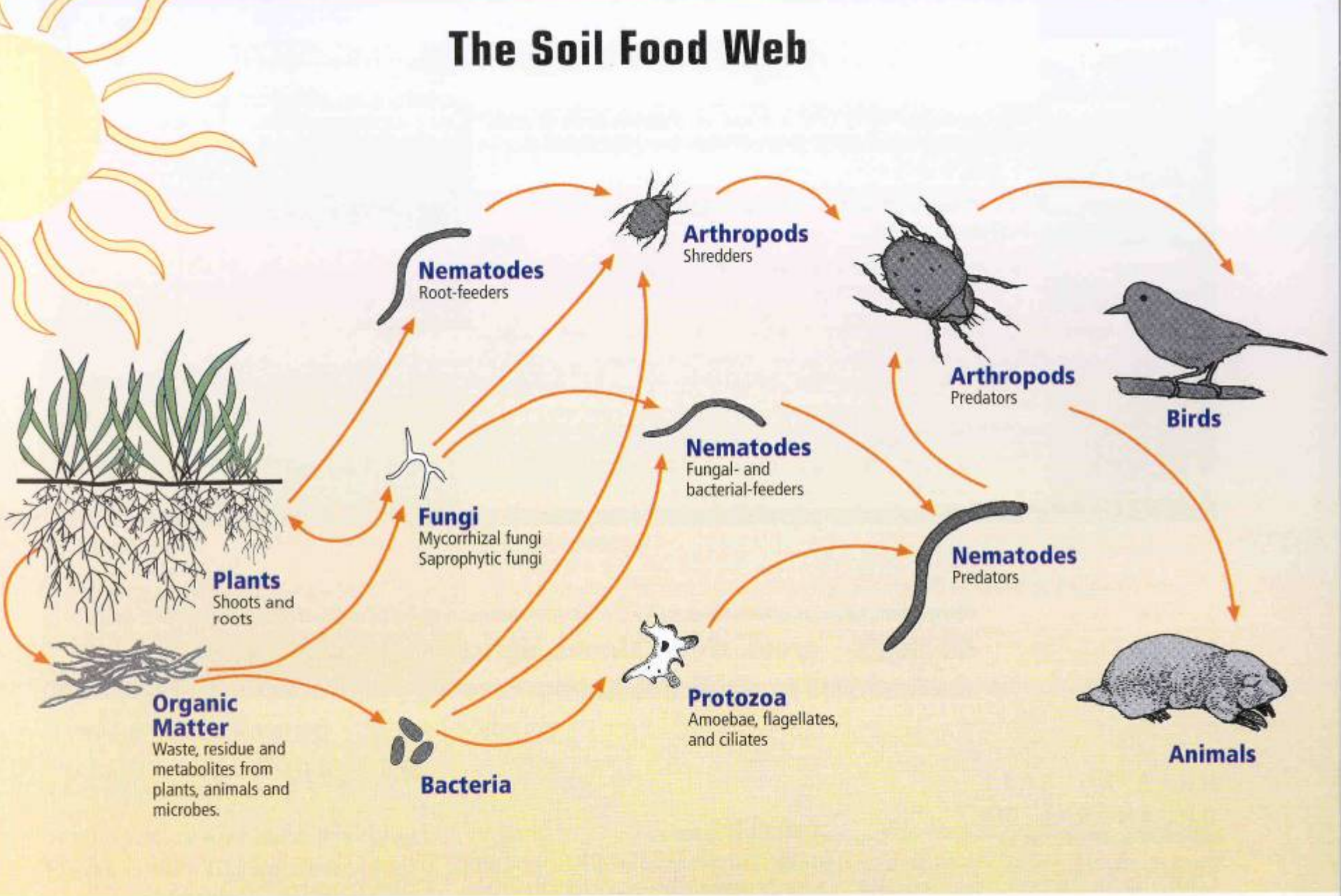
Root hair

Fungal hyphae



The Soil Food Web

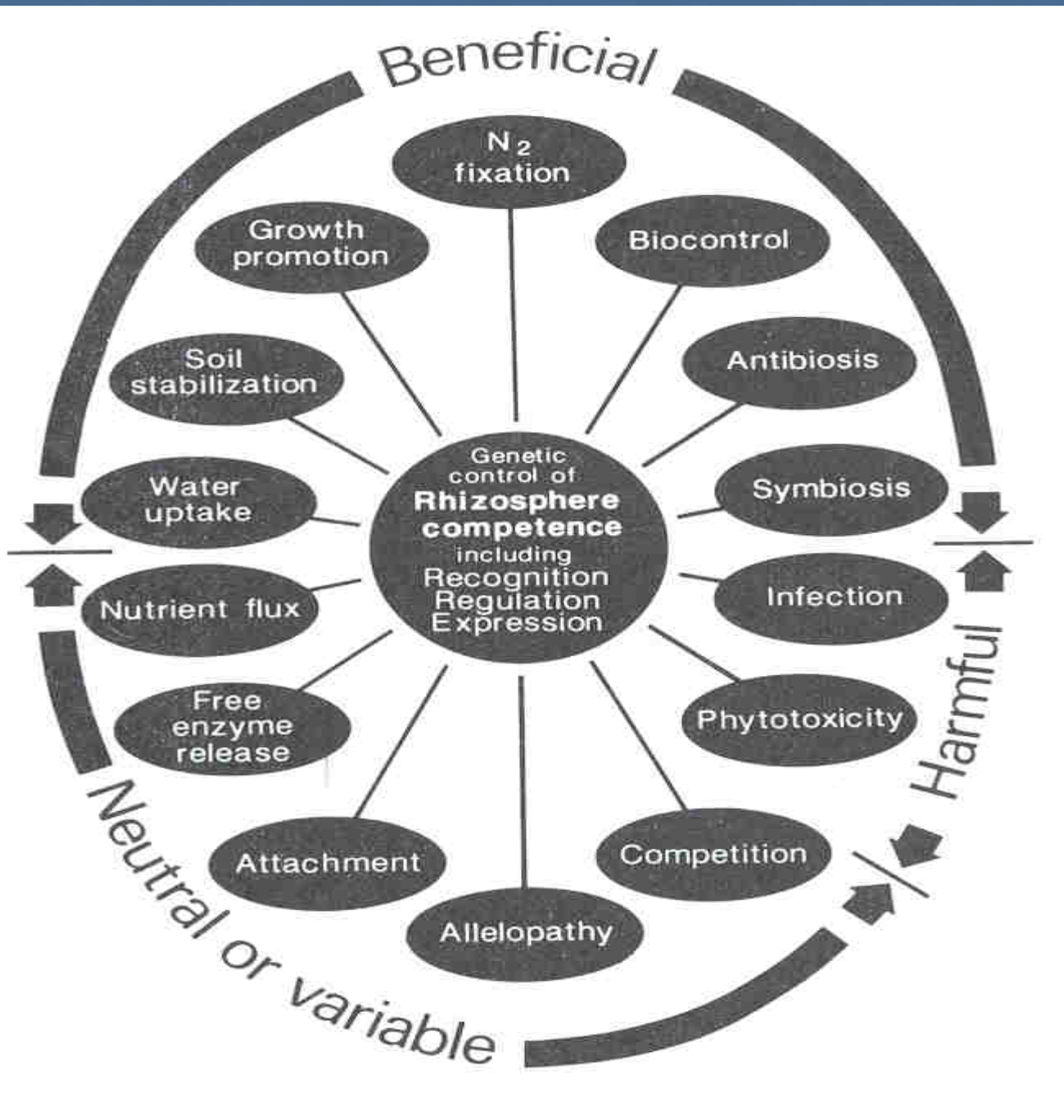


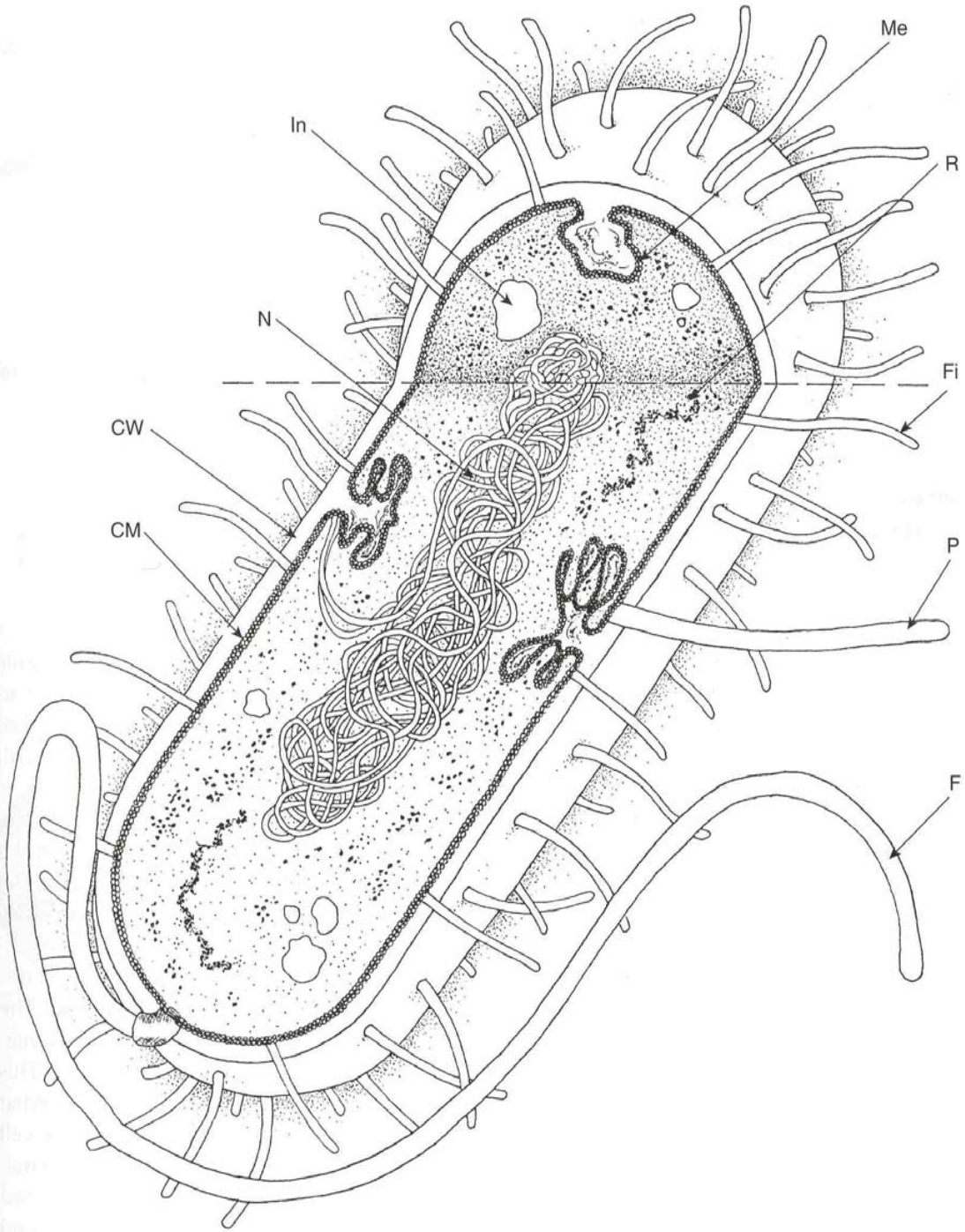
First trophic level:	Second trophic level:	Third trophic level:	Fourth trophic level:	Fifth and higher trophic levels:
Photosynthesizers	Decomposers Mutualists Pathogens, Parasites Root-feeders	Shredders Predators Grazers	Higher level predators	Higher level predators

Soil Bacteria

Kingdom Bacteria

- Prokaryotes
- Few diagnostic features
- Classified at first on metabolic capabilities, now on 16S rRNA sequence
- Saprophytes, pathogens, autotrophs, and symbionts


Beneficial
N_2 fixation
Growth promotion
Biocontrol
Soil stabilization
Antibiosis
Water uptake
Genetic control of
Rhizosphere competence
including
Recognition
Regulation
Expression
Symbiosis
Nutrient flux
Infection
Free enzyme release
Phytotoxicity
Attachment
Competition
Allelopathy
Harmful
Neutral or variable

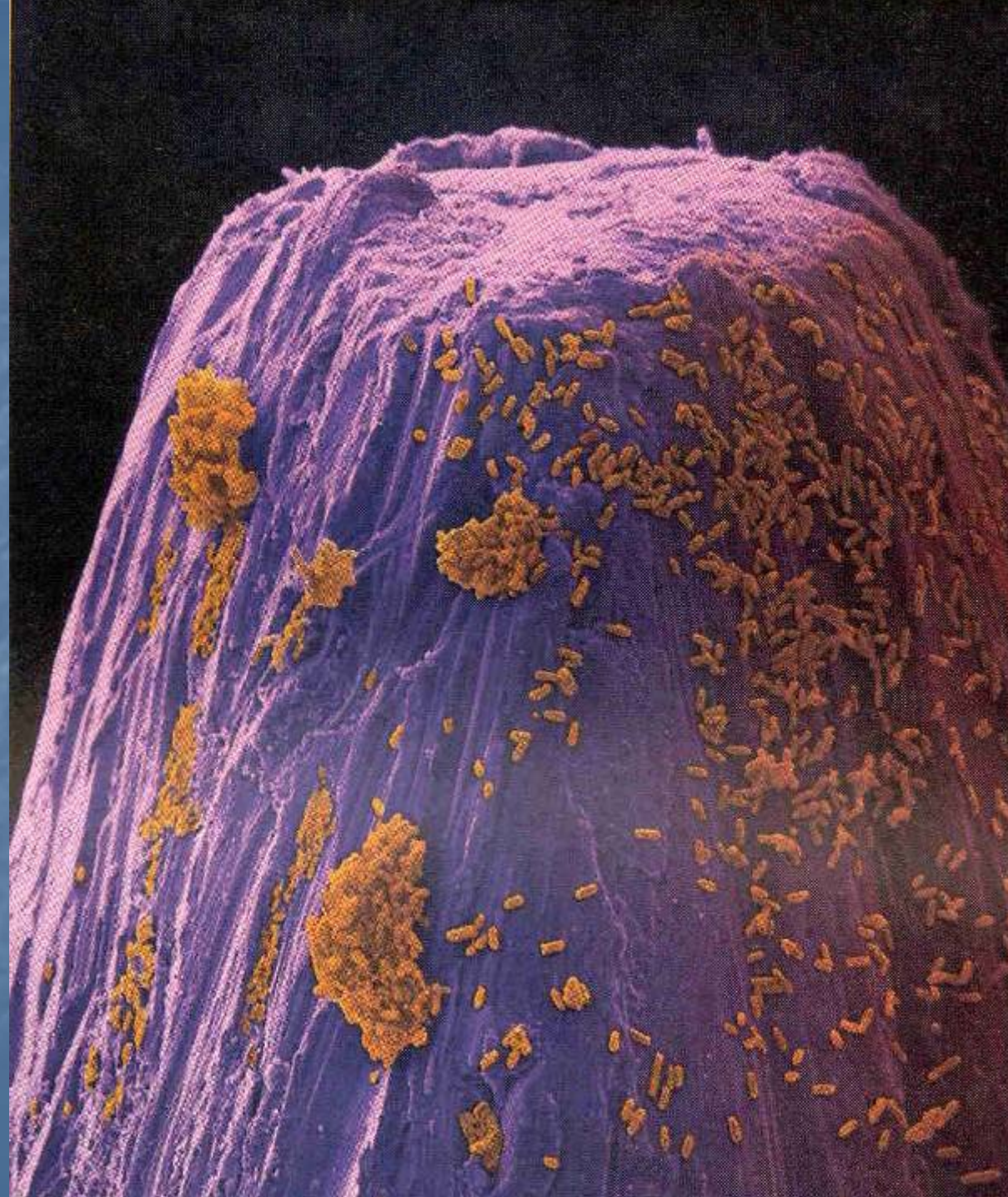


Bacterial cell

N = nucleoid
CW = cell wall
CM= cell membrane
R = 70S ribosome

F = flagellum
P = pilus
Fi = fimbriae
In = inclusion
Me = mesosome

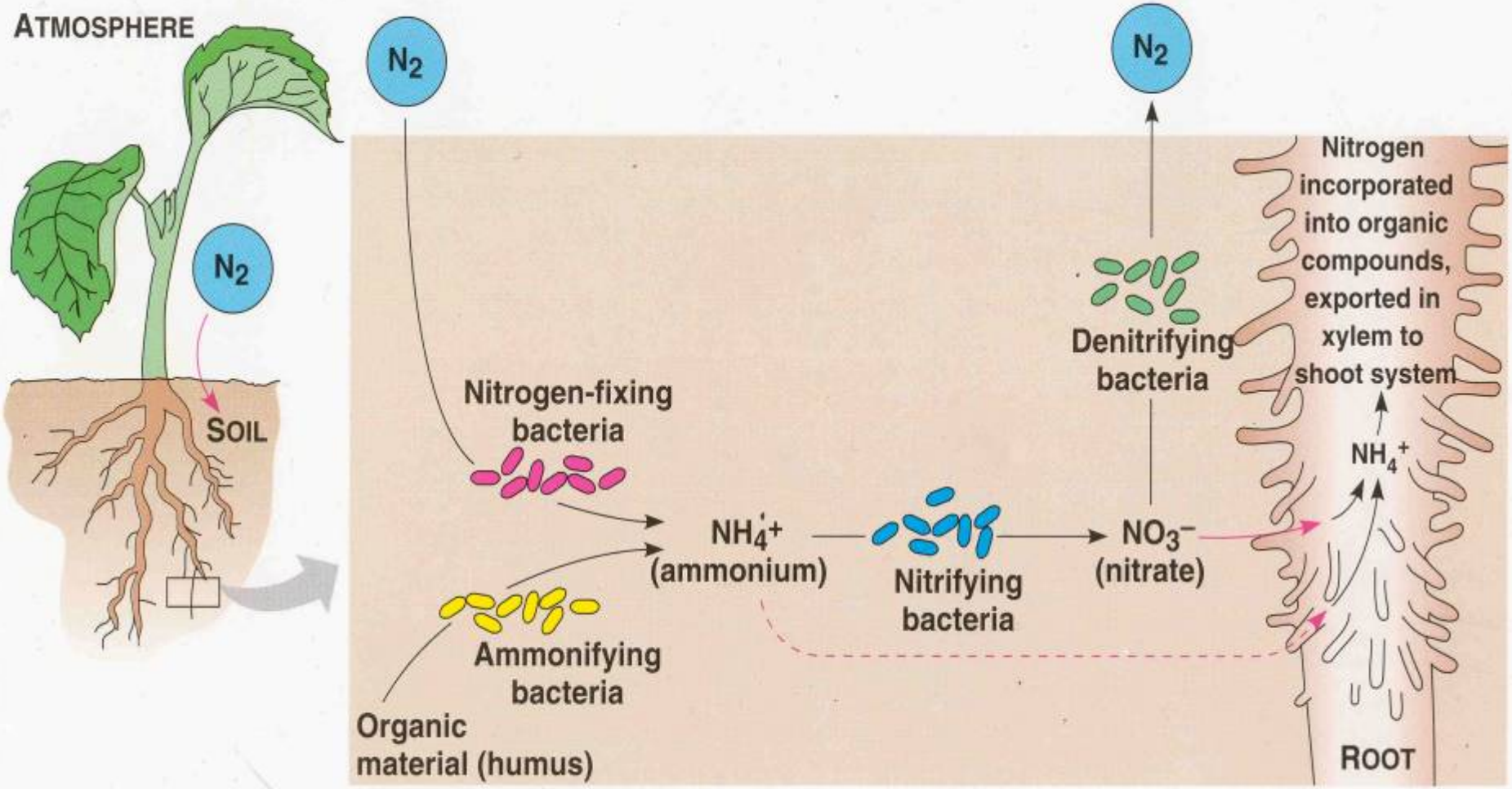
Bacteria on the head of a pin



Biosphere 2

- Failed because of high CO_2 levels
- Forgot about the soil microbes!
- Weren't able to recreate a functioning soil environment

Bacterially mediated nitrogen transformations



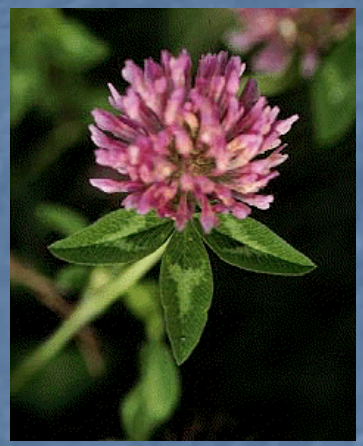
Nitrogen Fixation

- N_2 in the atmosphere and NH_4 in the lithosphere are the major N pools
- N_2 must be "fixed" by prokaryotes into ammonia to be used for metabolic processes.
- N is a primary constituent of proteins and nucleic acids, therefore essential for life.

Soybean root nodules

- Bacteria provide the plant with mineralized N
- Plant provides the bacteria with a source of C

Types of Symbioses: Agricultural



Trifolium pratense (red clover) – *Rhizobium* (bacterium): important forage crop

Pisum sativum (pea) – *Rhizobium* (bacterium): important crop

Glycine max (soybean) – *Bradyrhizobium* (bacterium): important crop, forage, oil production, soybeans, etc.

Types of Symbioses: Agricultural

Azolla (aquatic fern) - *Anabaena azollae* (cyanobacterium): important in rice cultivation

Jatun Sacha agroforestry station, Ecuador

Inga (tropical tree) - *Rhizobium* (bacterium): Important canopy tree for shade grown coffee, could contribute significant N

Types of Symbioses: Trees

Alnus rubra (red alder) – *Frankia* (bacterium): important sucessional species in forests

Casuarina equisetifolia (tropical tree) – *Frankia* (bacterium): common in the Carribean

Types of Symbioses: Unusual

Lobaria pulmonaria (lichen) – *Nostoc* (cyanobacterium): important in forest ecosystems

Sesbania rostrata (legume) – *Rhizobium* (bacterium): stem nodules that can also photosynthesize

Inoculants

J. Thies PhD thesis 1987

Soil Fungi

Roles of fungi in the soil

- Soil aggregate stability
- Increased nutrient availability for plants (Mycorrhizal symbiosis)
- Nutrient source for other soil organisms
- Decomposers (especially in forest systems)
- Some are predatory!

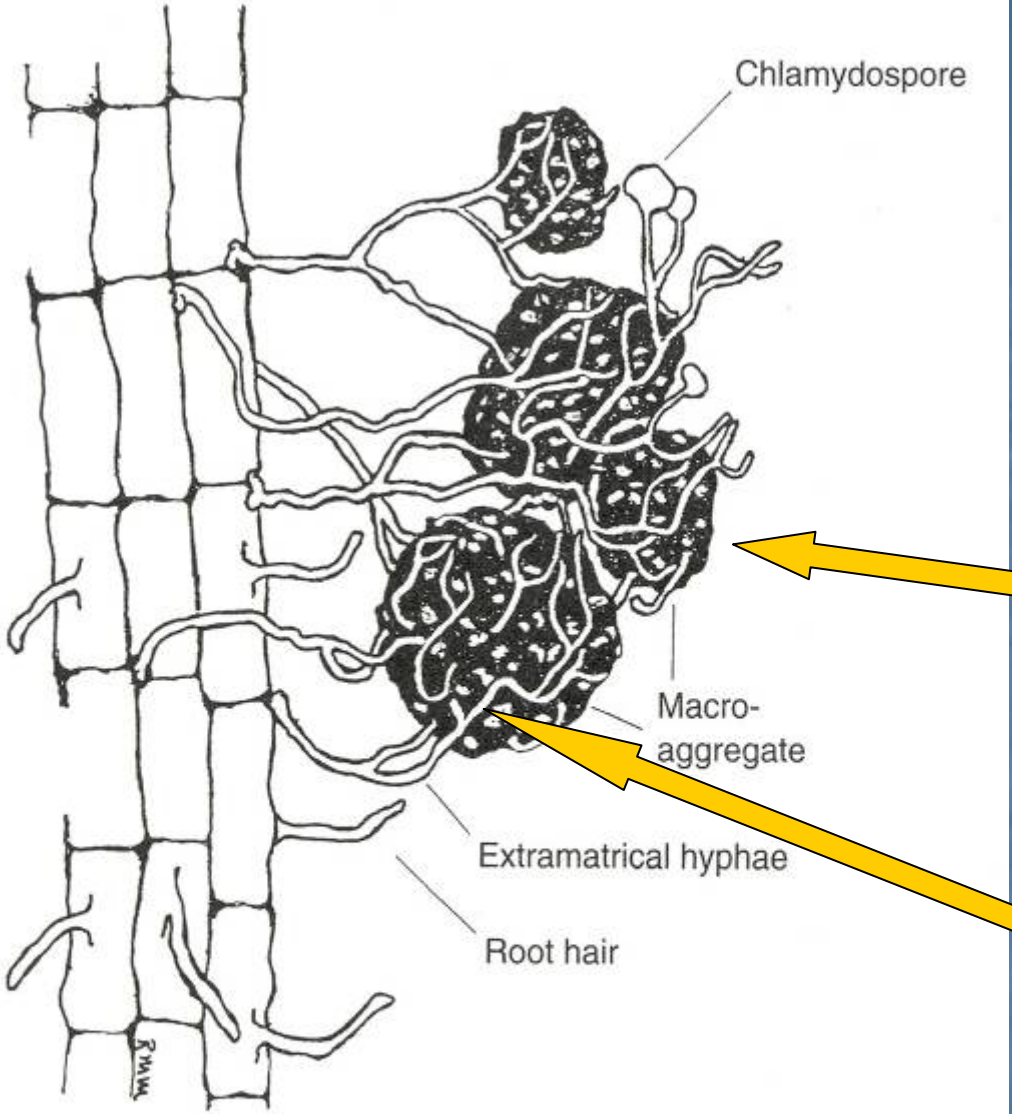


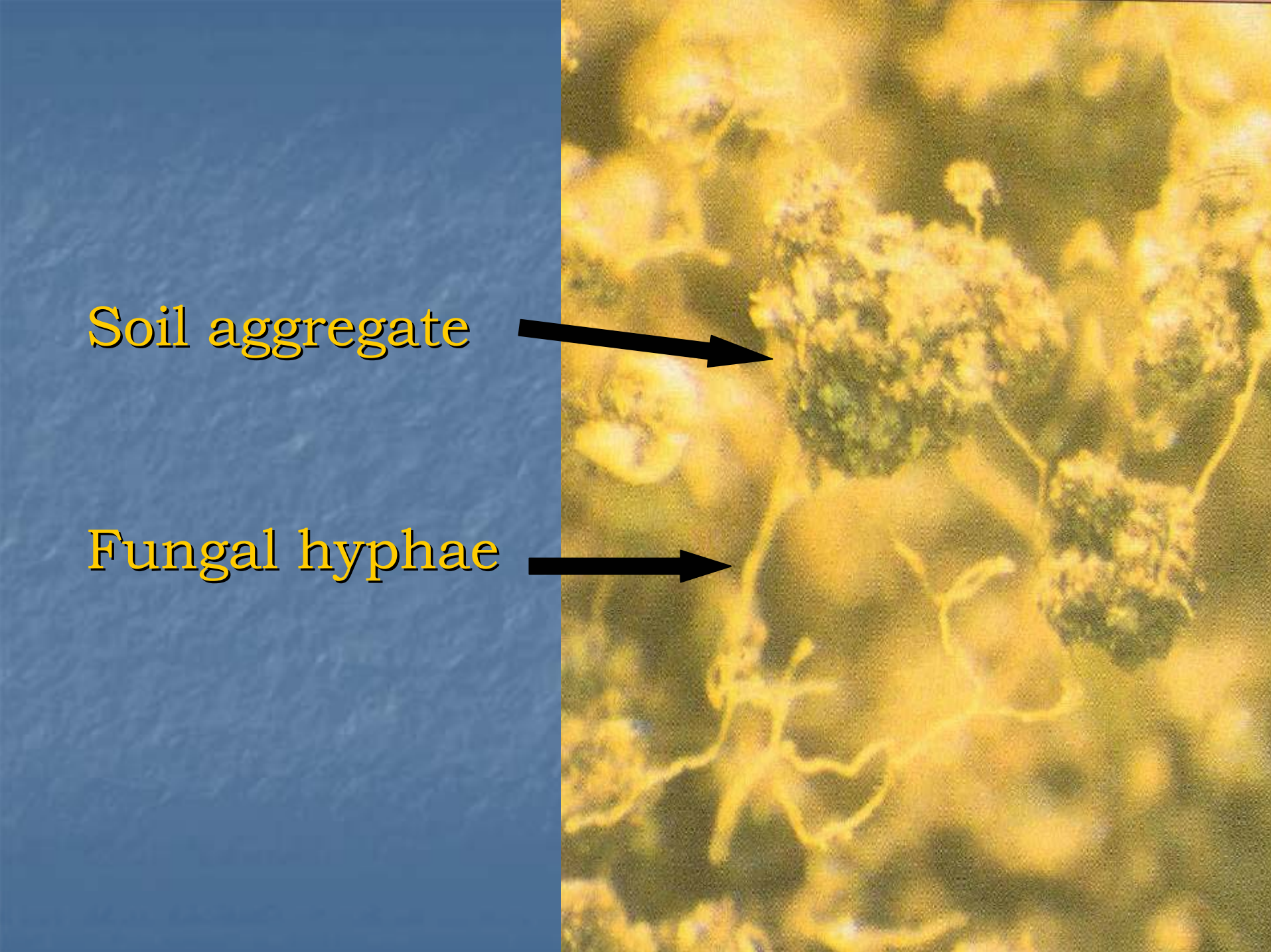
Figure 18–8 Diagram showing extramatrical mycorrhizal hyphae enmeshing soil microaggregates, leading to development of macroaggregates and soil stabilization within the rhizosphere. *From Miller and Jastrow (1992). Used with permission.*

Soil aggregate stability

Soil aggregate

Fungal hyphae

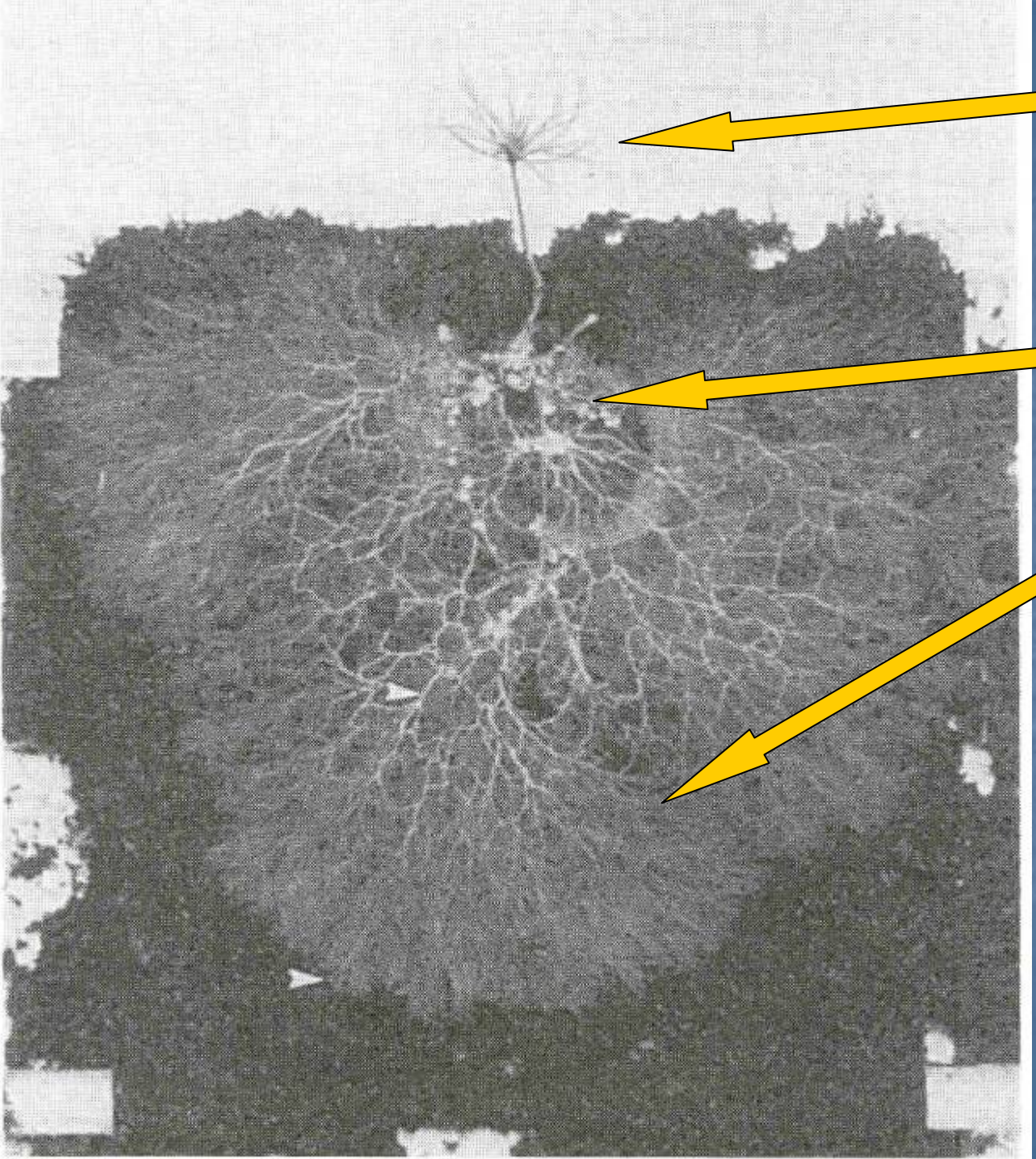
Glomalin: chemical produced by some fungi that acts as a glue in aggregates


Soil aggregate
Fungal hyphae

Mycorrhizal Symbiosis

- Main types: Ecto-, Endo-
- Plant benefits
  - improved nutrient status
  - protection from desiccation and salts
  - pathogen and toxic metal protection
- Fungus benefits
  - source of energy and carbon
  - competitive advantage
- Increased soil stabilization

Mycorrhizae means “fungus root”



Pine seedling

roots

Mycorrhizal hyphae

Increased surface area for nutrient uptake

Paul and Clark, 1994

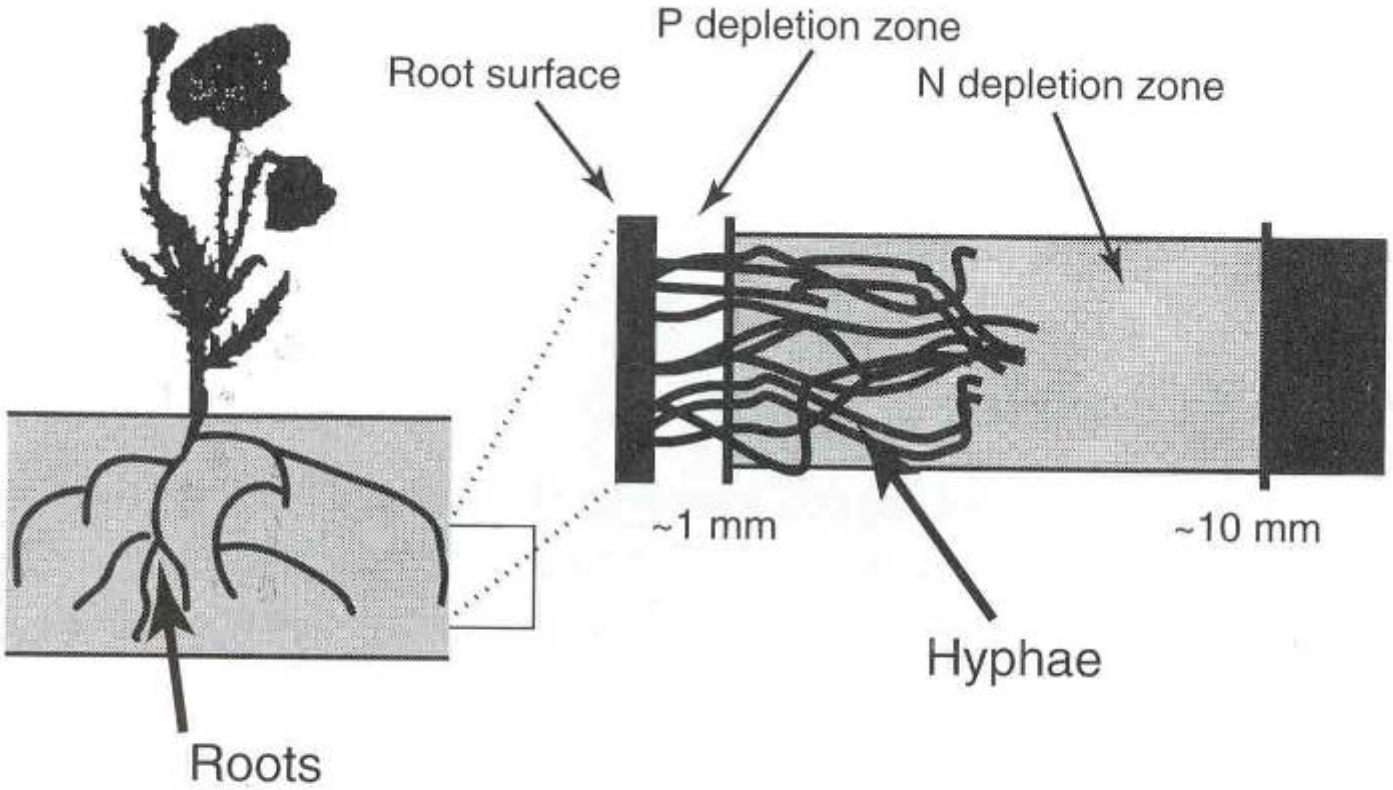


Figure 18–7 Diagram of how of a depletion zone develops next to the root surface. A narrow depletion zone (e.g., 1 mm) usually develops for phosphate, while a wide depletion zone (e.g., 10 mm) develops for nitrate. Mycorrhizal hyphae can generally grow beyond the phosphorus depletion zone, but not the nitrogen depletion zone.

Ion diffusion

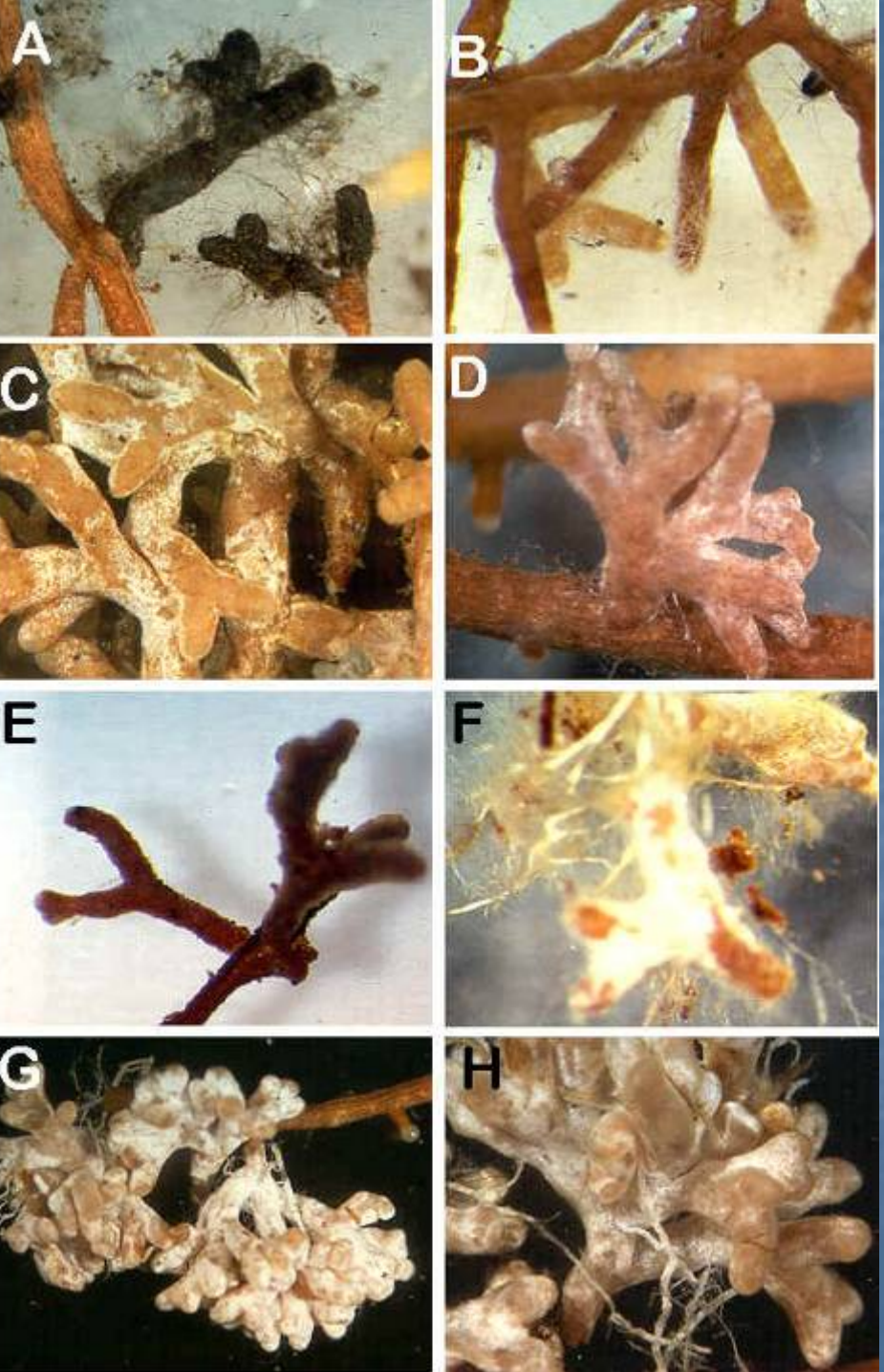
- Diffusion coefficients
  - NO_3^- = 10^{-6} cm^2 sec^{-1}
  - NH_4^+ = 10^{-7} cm^2 sec^{-1}
  - PO_4^{3-} = 10^{-8} cm^2 sec^{-1}
- Concentration
  - NO_3- >> PO_4^{3-}

Enhanced nutrient uptake with mycorrhizae

Table 29-1 Effect of mycorrhizae on nutrient uptake in onion.

	Total Nutrient Uptake Per Plant							
Treatment	**P**	**Ca**	**Mg**	**Na**	**K**	**Zn**	**Mn**	**Fe**
	mg					**µg**		
Control	0.39	8.7	0.46	0.25	10.9	38	69	171
Glomus fasciculatus	4.42	25.2	2.49	2.76	35.9	112	106	412
Glomus monosporus	3.26	14.4	1.46	1.36	22.5	79	71	432

(Adapted from Ojala et al. 1983)

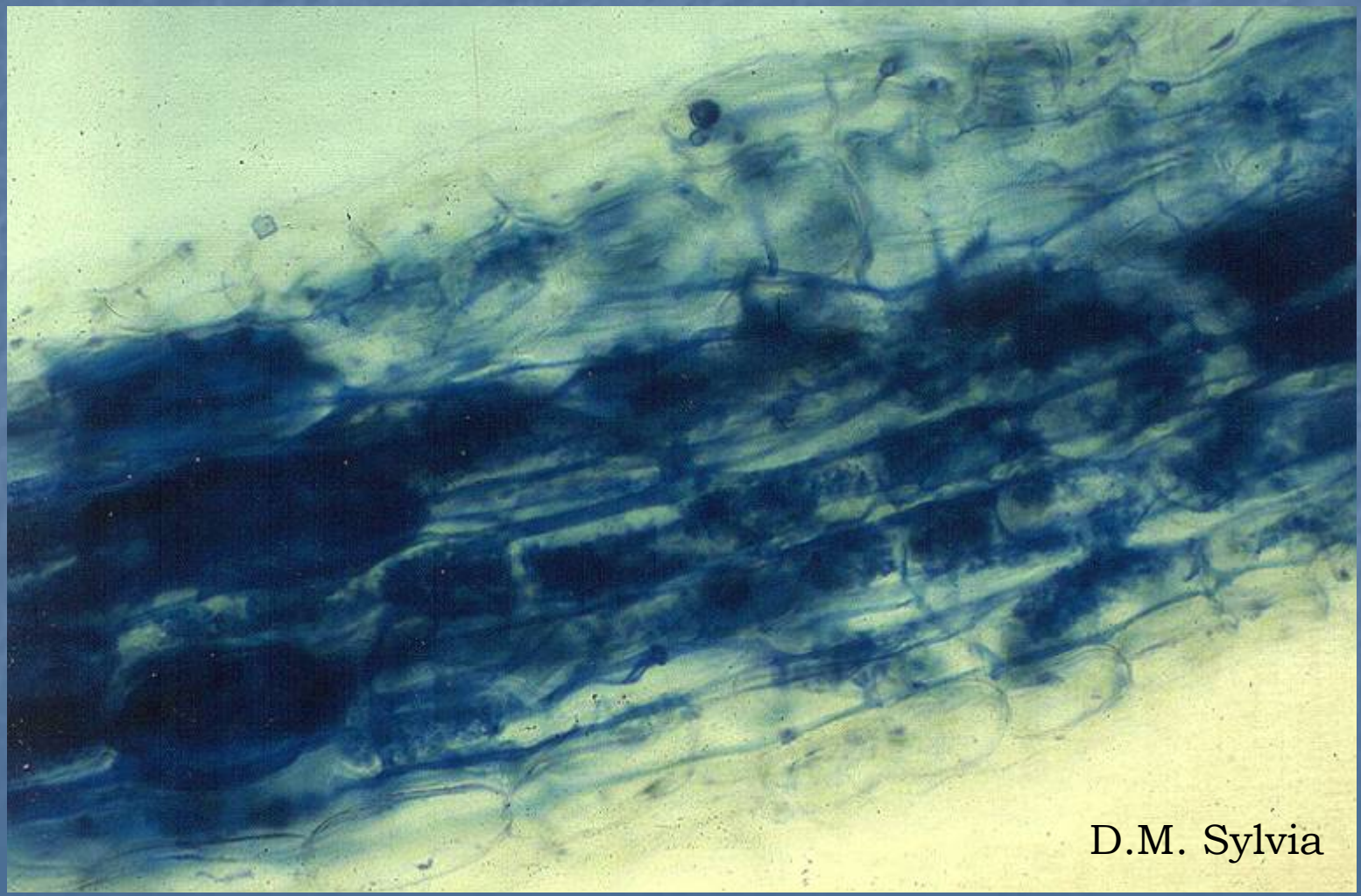


Ectomycorrhizae "short-roots" of pine

Ecto = "outside" root

D.M. Sylvia

Endomycorrhizae
Endo = “inside” root



Endomycorrhizae

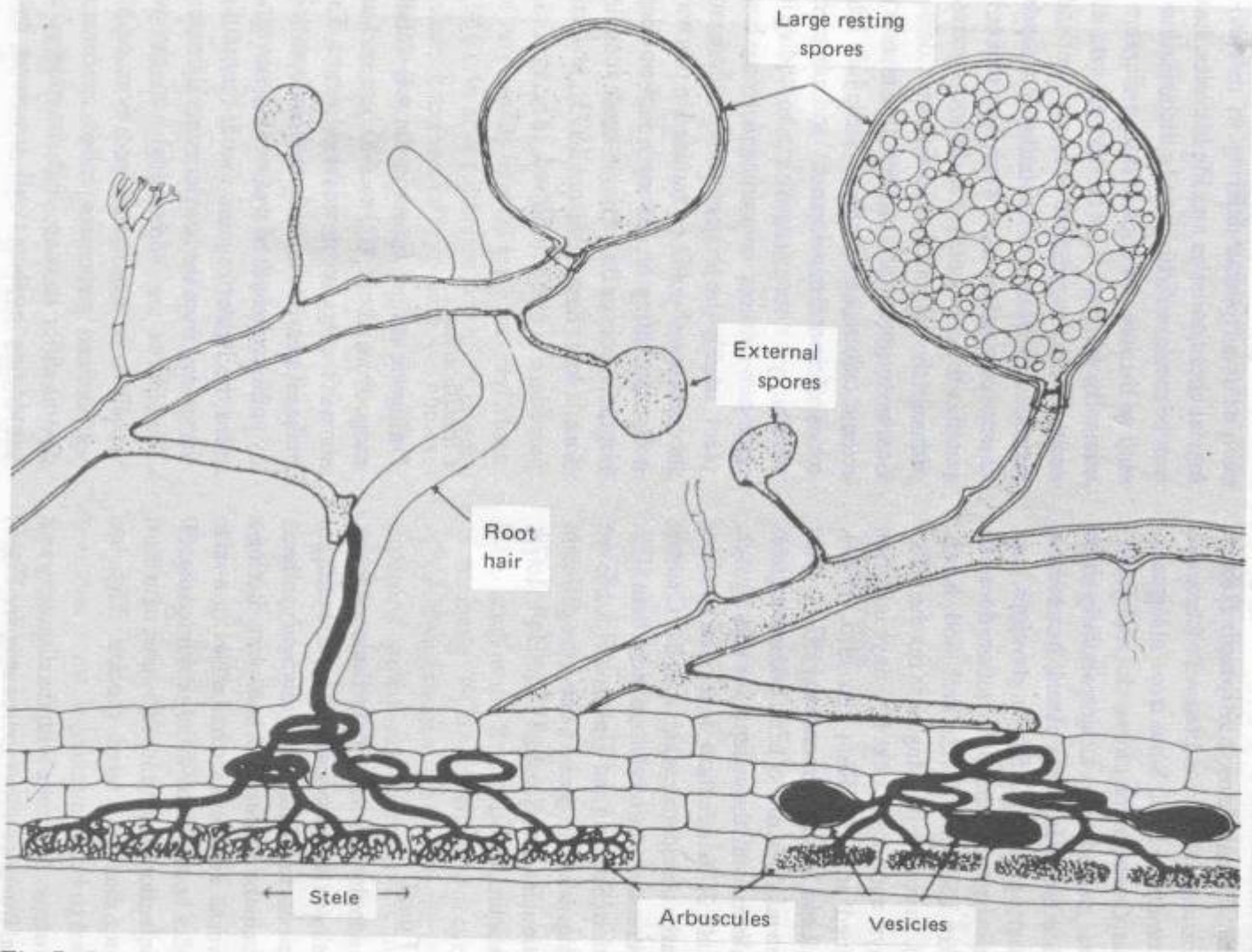
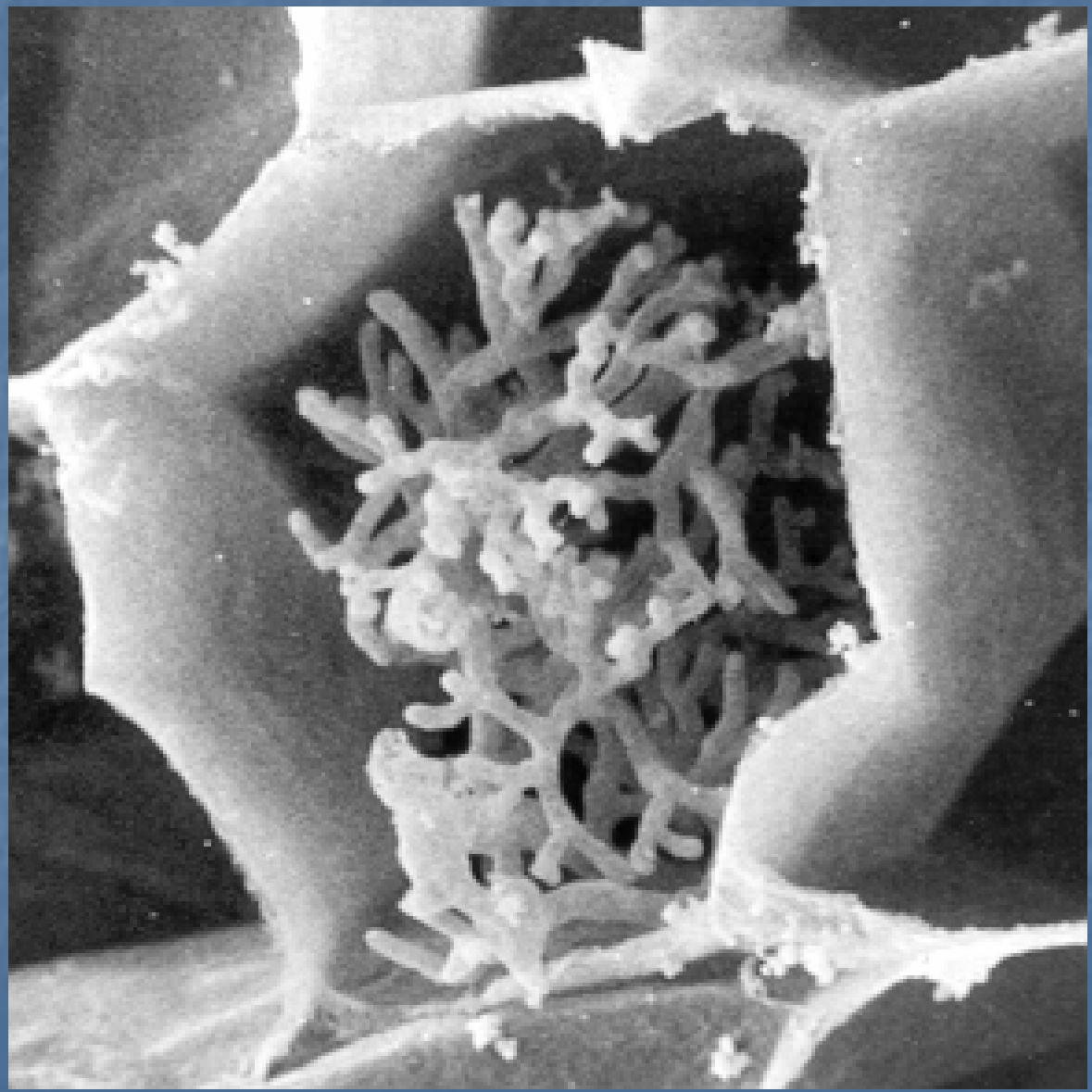


Fig. 7. Diagram of resting spores and soil mycelium and their relationship to a mycorrhizal root. (*Courtesy T. H. Nicolson, from Nicolson, 1967*)

Endomycorrhizae

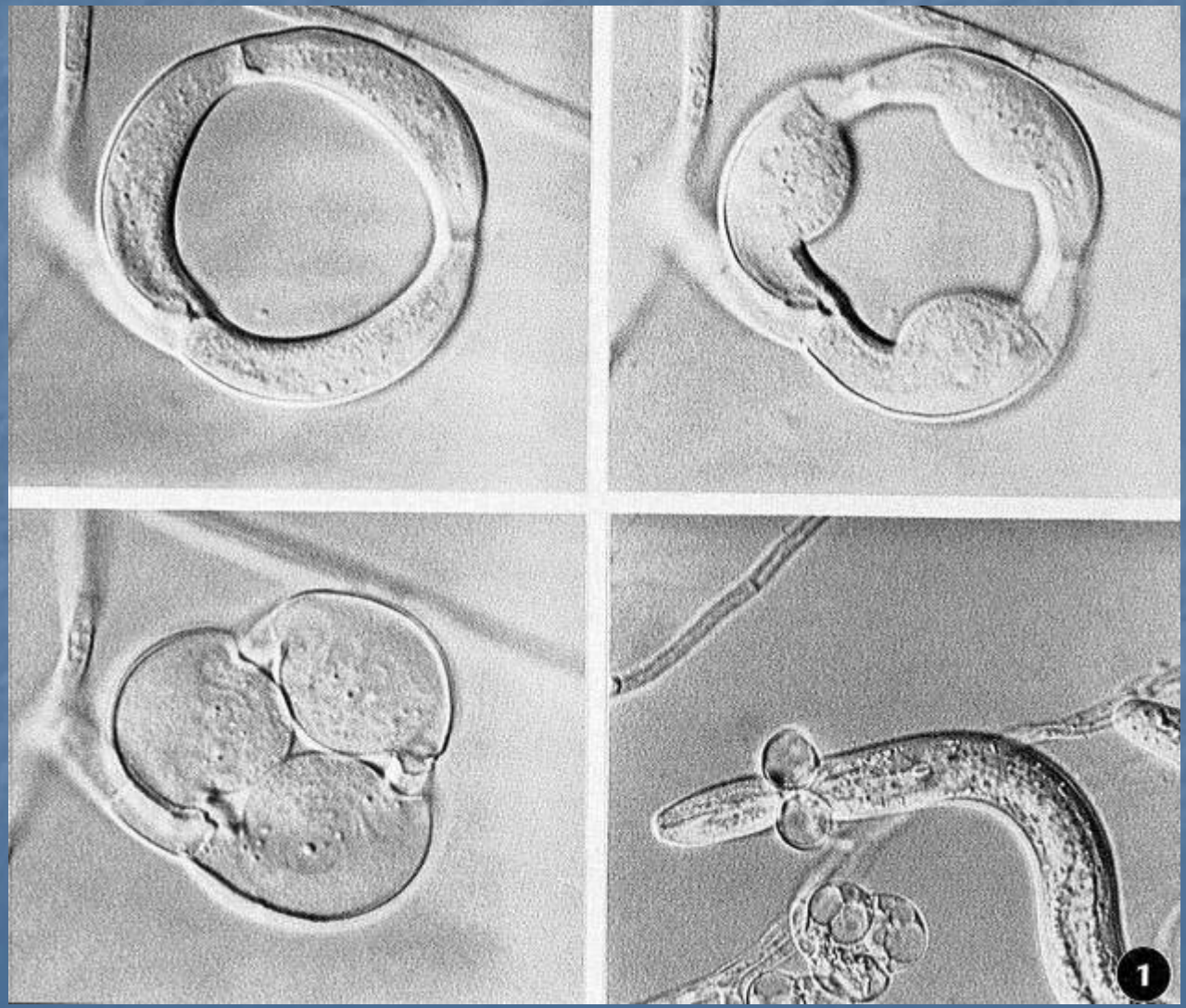


Arbuscules inside of a plant cell – increased surface area for nutrient exchange

Kinden and Brown, 1975

Benefits of inoculation

Nematode trapping fungi



hyphae constrict using water pressure, then digest the nematode

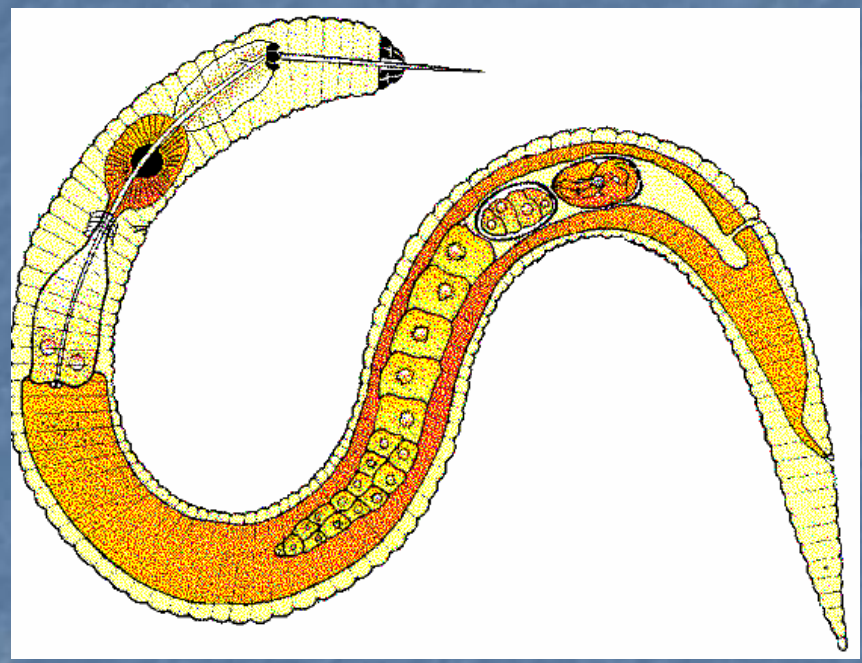
Nematodes

Roles of nematodes in soil

- Feed on bacteria, fungi and protozoa
  - Control bacterial numbers and population structure
  - Release large amounts of N while feeding and upon death
  - Help maintain plant available N
- Plant and animal parasites

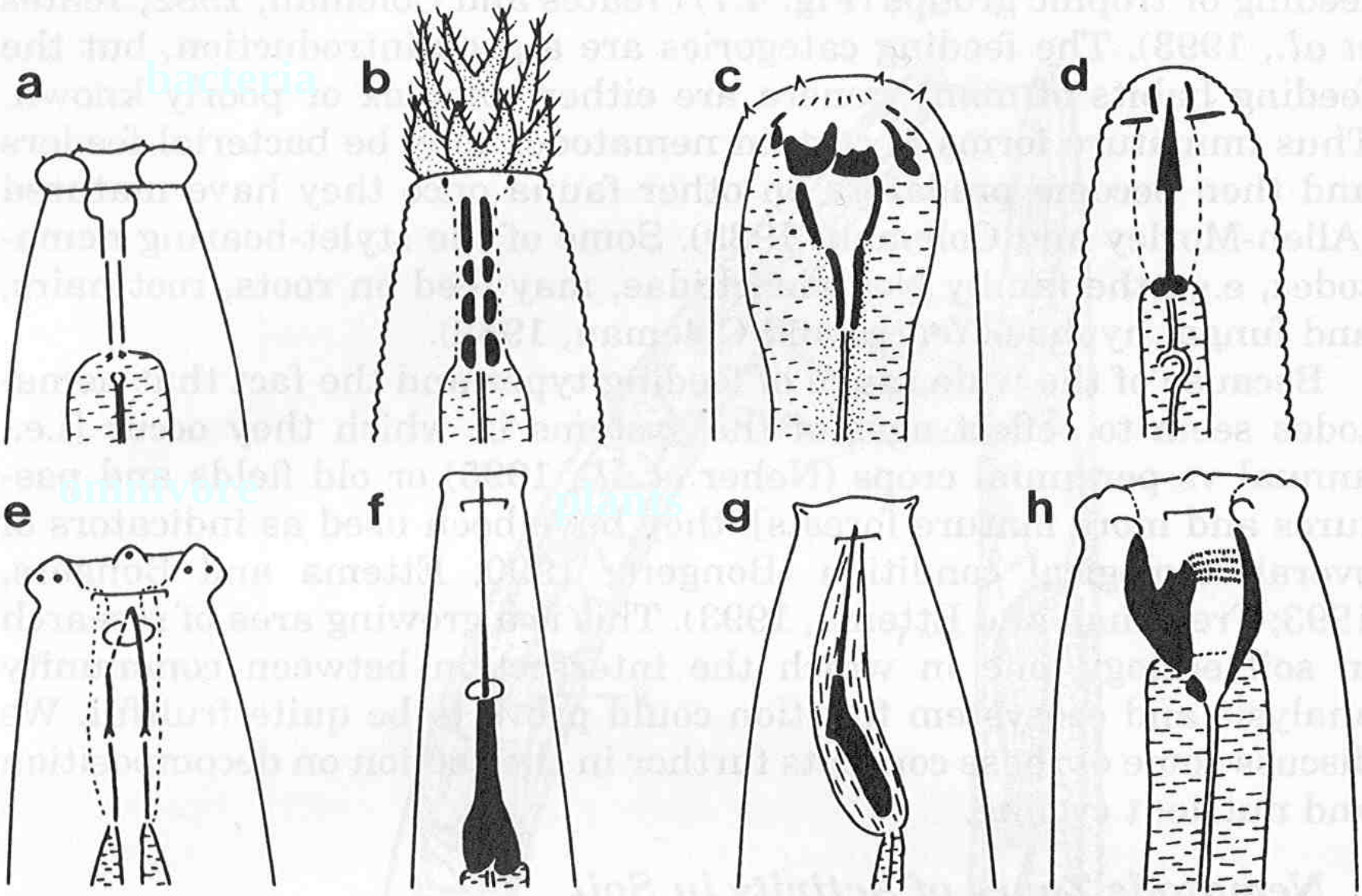
Nematodes

- vermiform animals
- small (300 to 500µm in size)
- ubiquitous to all soils
- abundant
- water dependent
- diverse range of feeding strategies:
  - plant parasites
  - Bacterial and fungal feeders
  - predators or other nematodes
  - omnivores

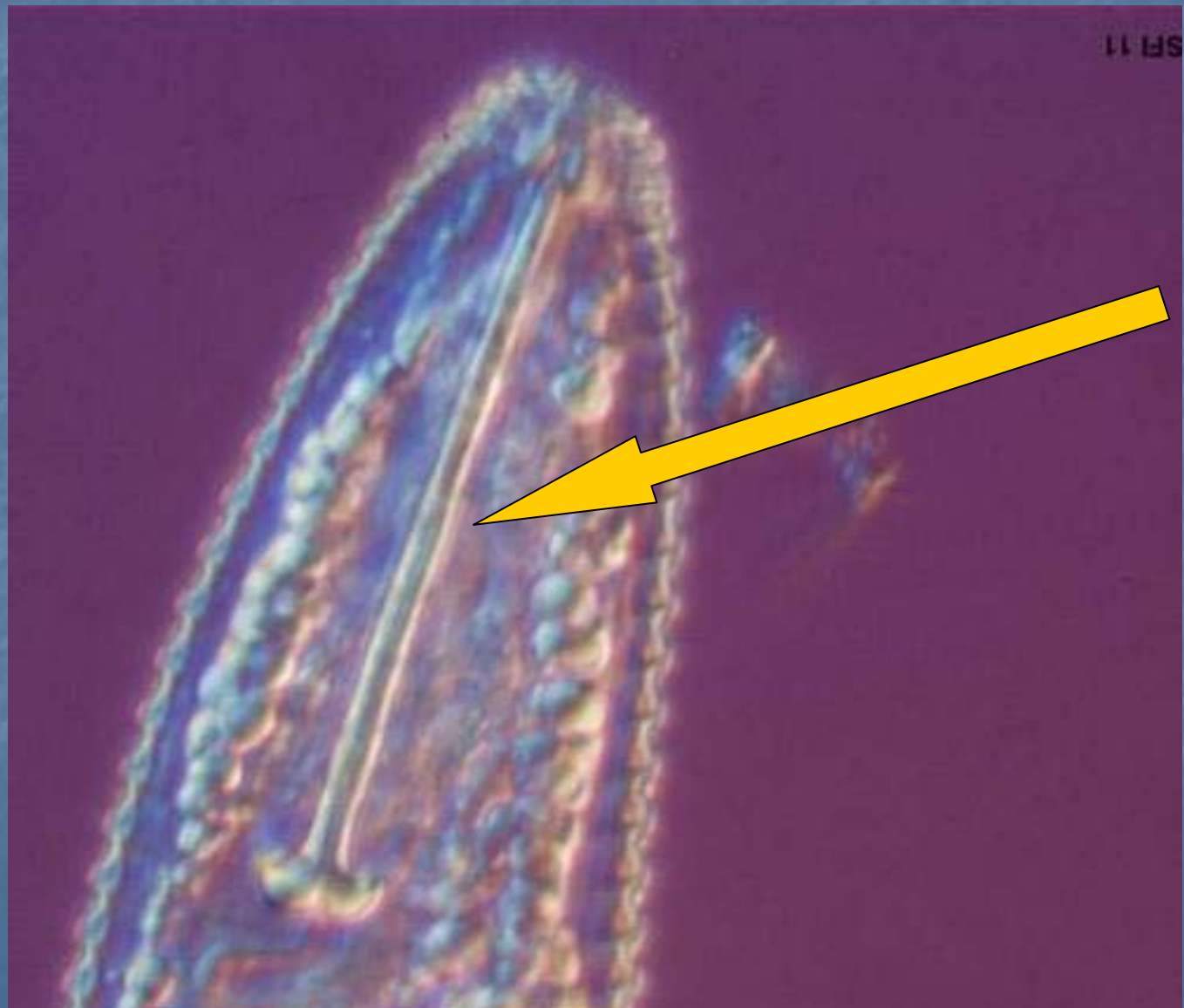


www.barc.usda.gov R. P. Esser

Specialized nematode mouthparts



Plant pathogenic nematode

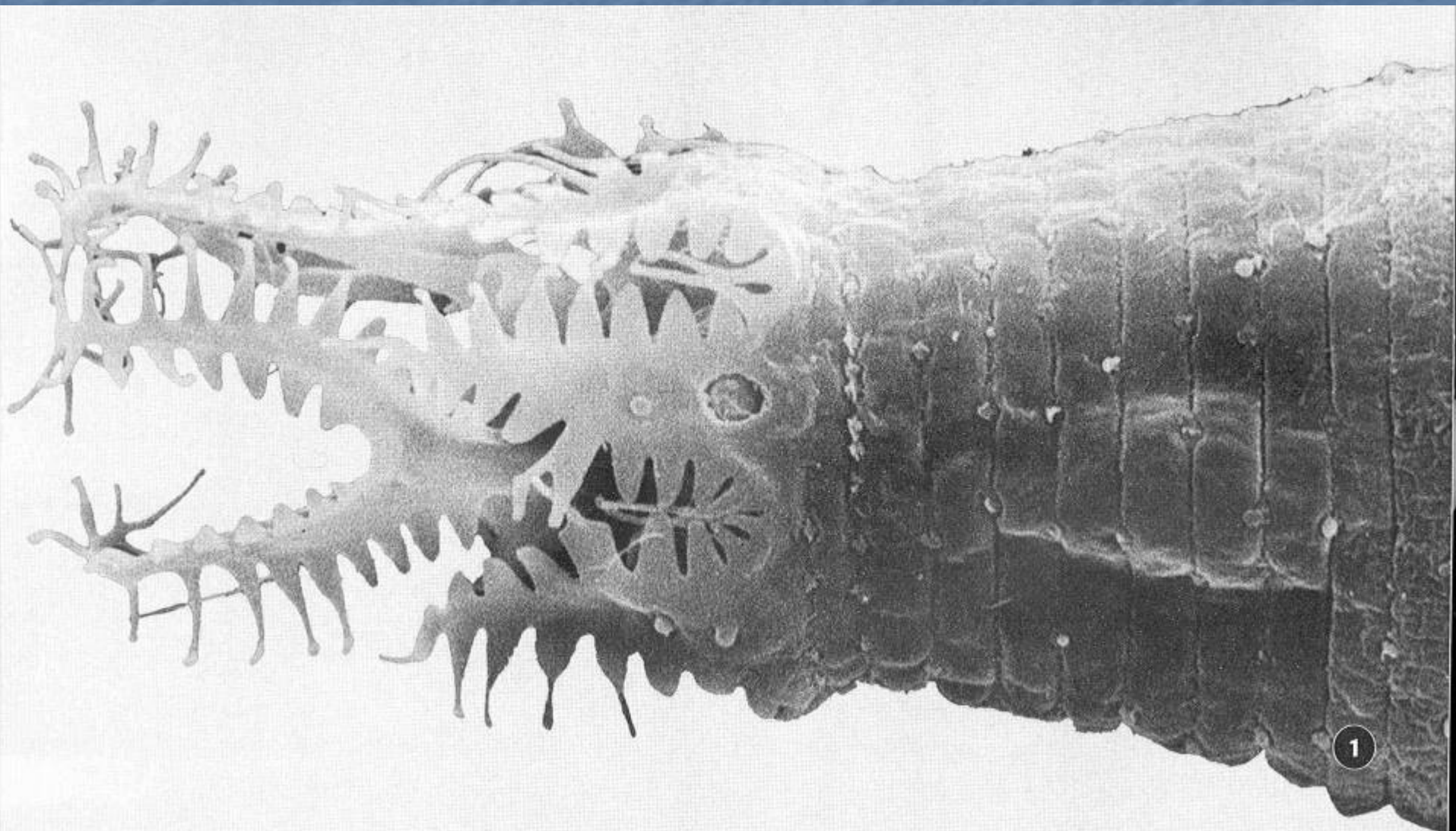


Stylet for piercing plant cell wall

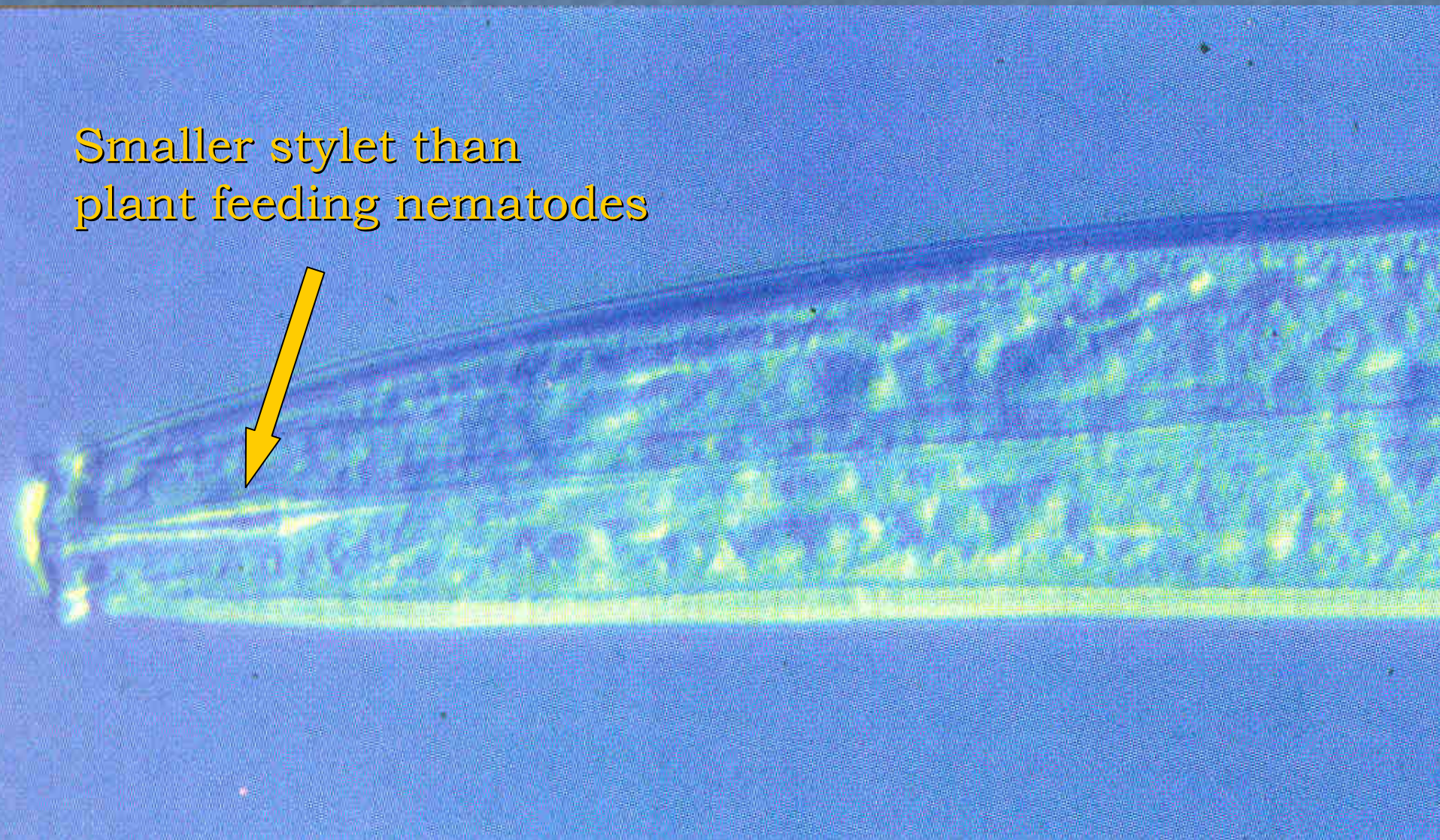
Bacterial Feeder

- 6 lips create a current to bring bacteria into their mouths

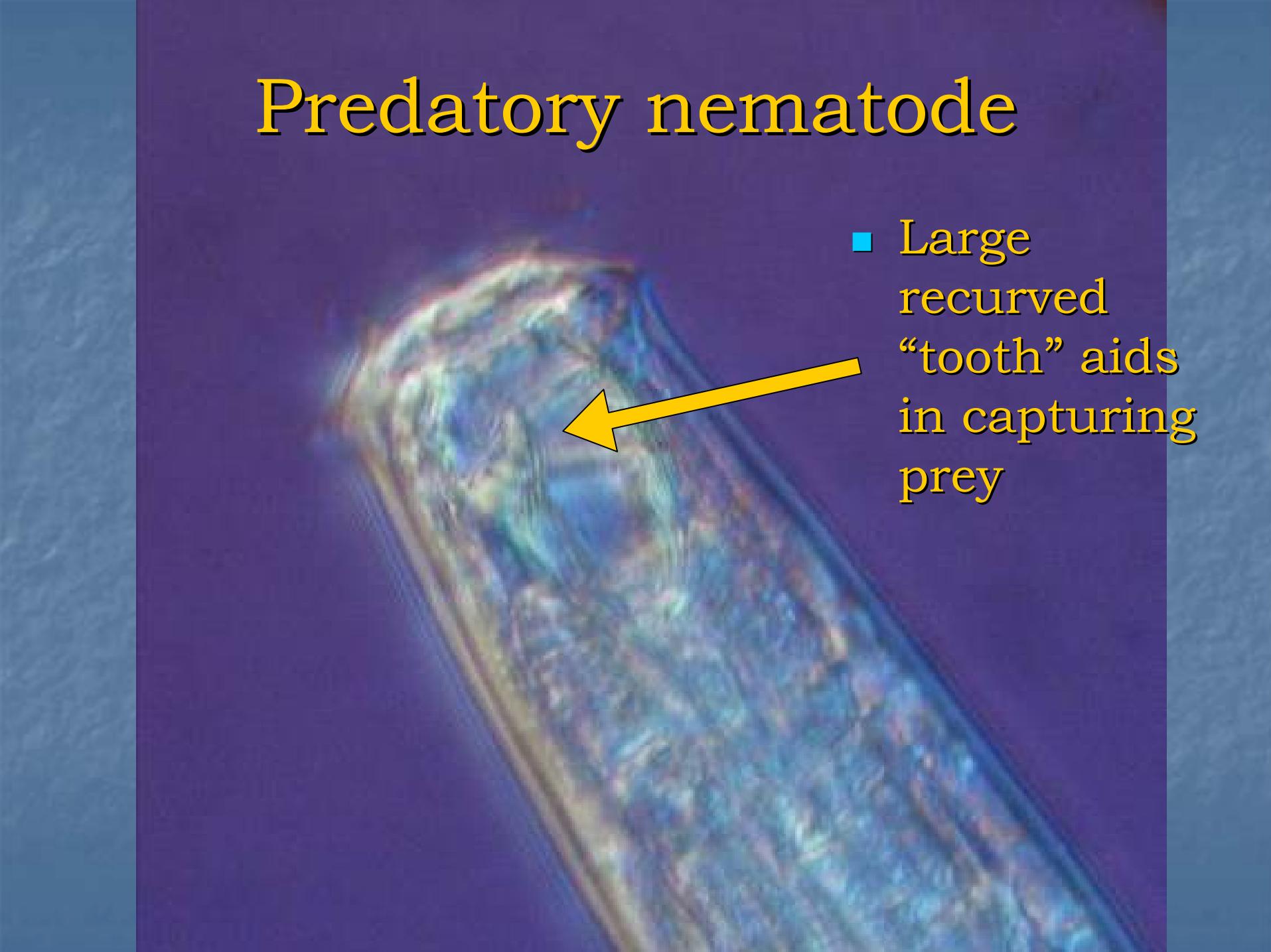
Scanning electron micrograph of bacterial feeding nematode



Fungal feeding nematode

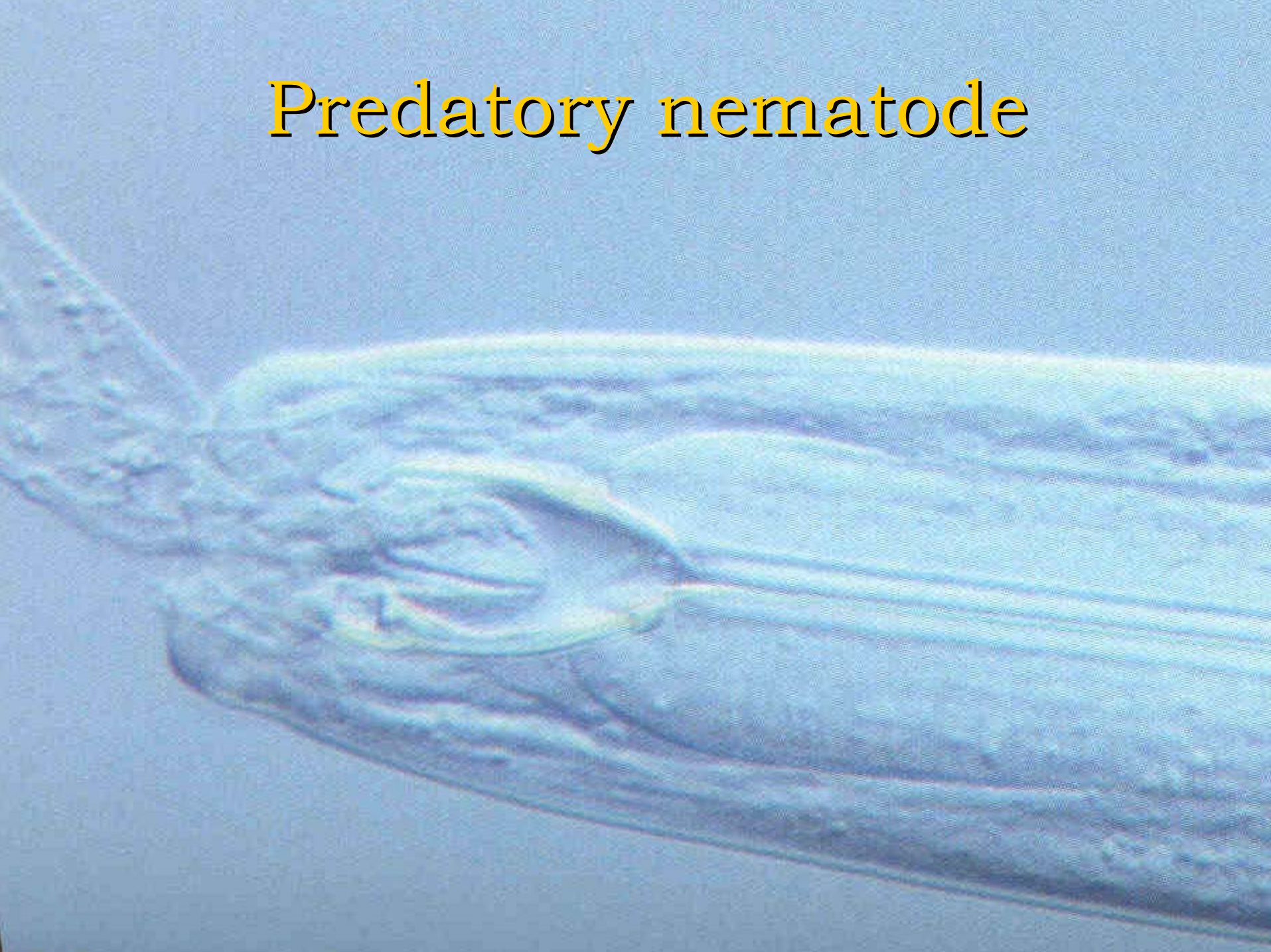


Predatory nematode



- Large recurved "tooth" aids in capturing prey

Predatory nematode



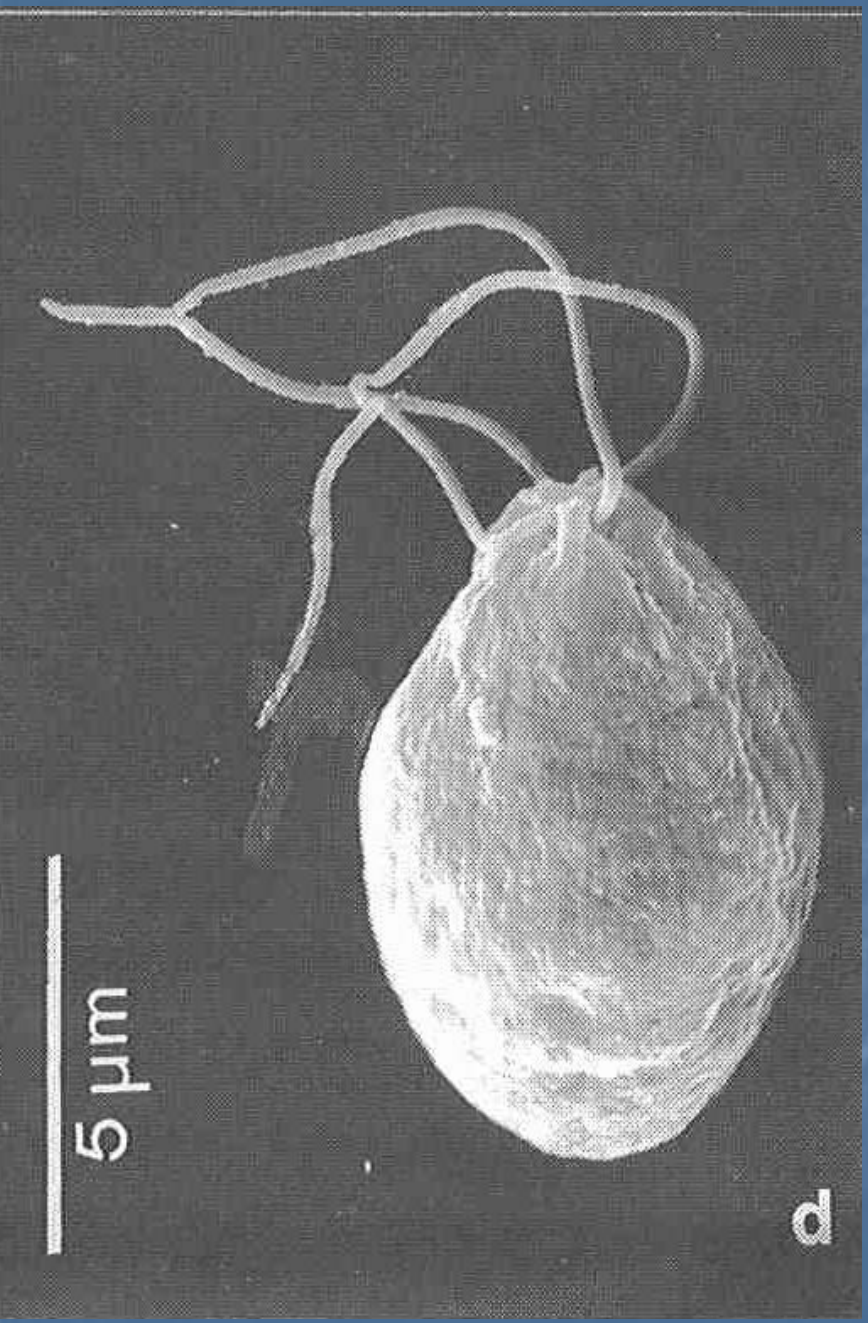
Protozoa

Protozoa

- Eukaryotes
- Unicellular animals
- No cell wall, can rapidly form cysts
- Widespread in soil and water
- Need water films for activity
- Large proportion of soil biomass
- Sexual and asexual reproduction

Types of Protozoa

- Flagellates
- Ciliates
- Amoebae
  - Testate
  - Naked

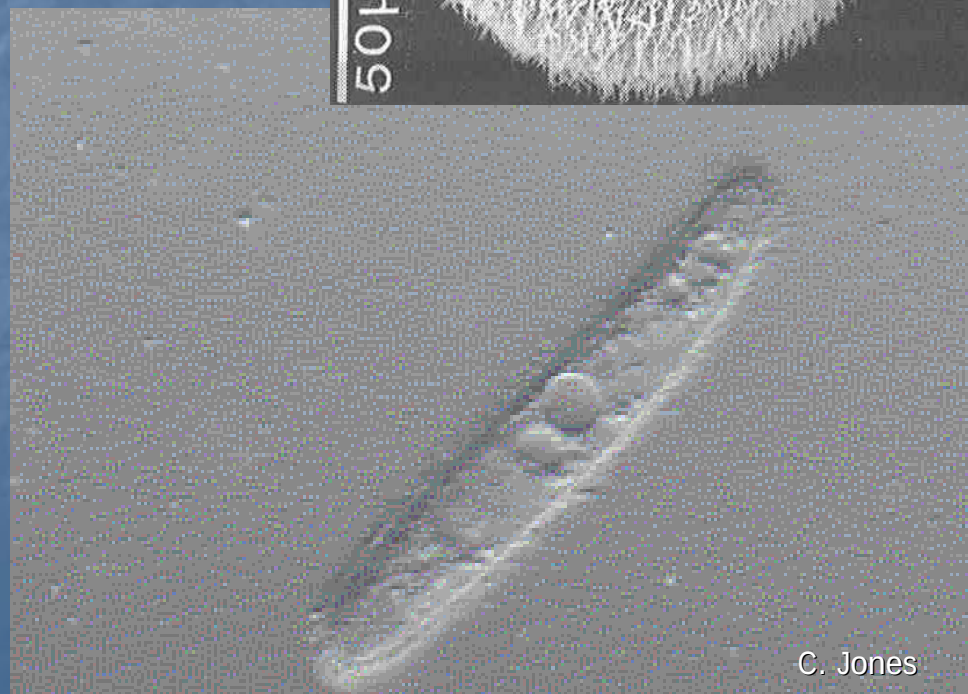


Flagellates

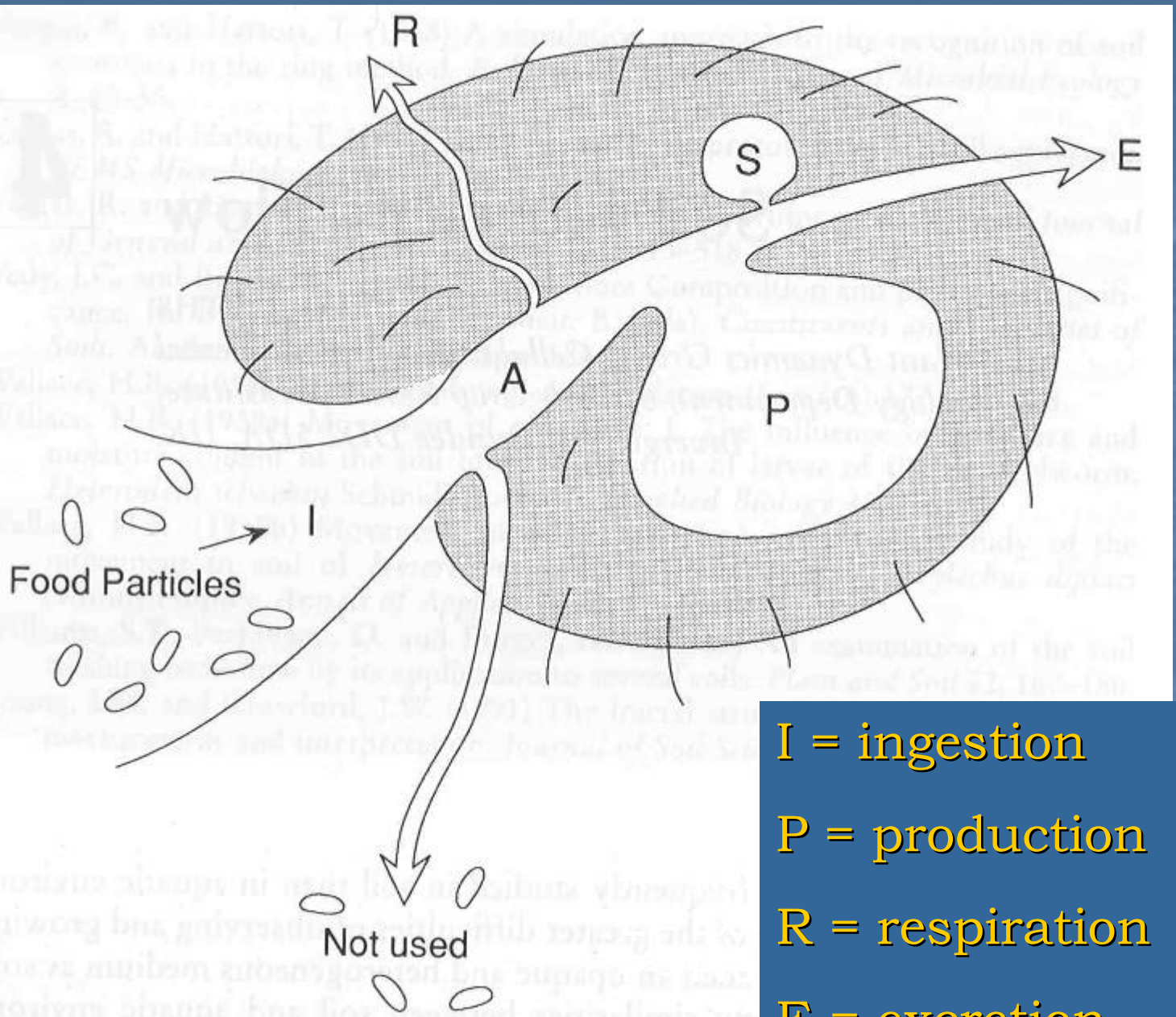
- Smaller than ciliates
- Live in freshwater and soil
- Phagotrophic (eat bacteria)
- Saprotrophic (eat decaying organic matter)
- Parasites of animals
  - *Trypanosoma, Giardia, Leishmania*

Ciliates

- Motile by means of numerous cilia
- Organized into a coordinated locomotor system
- Phagotrophic: eat flagellates
- Live in freshwater, soil, rumen (animal intestinal systems)
- *Paramecium*



C. Jones



I = ingestion

P = production

R = respiration

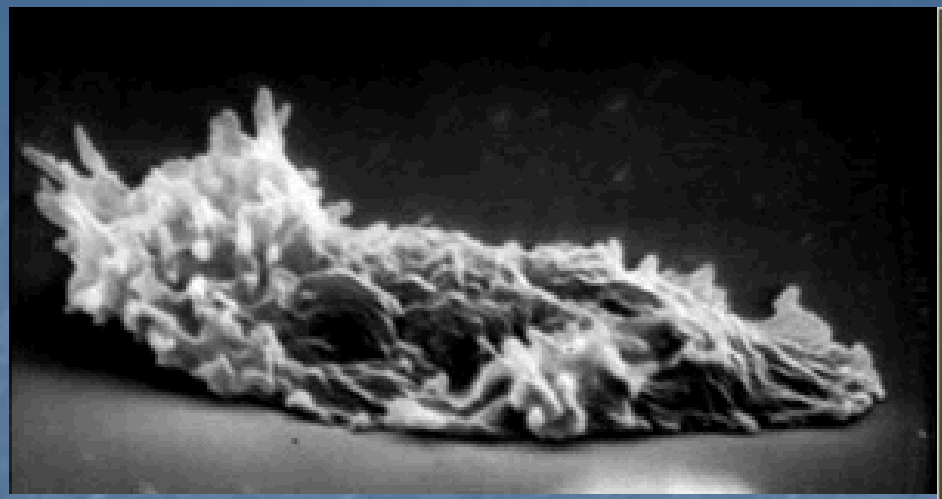
E = excretion

N mineralization

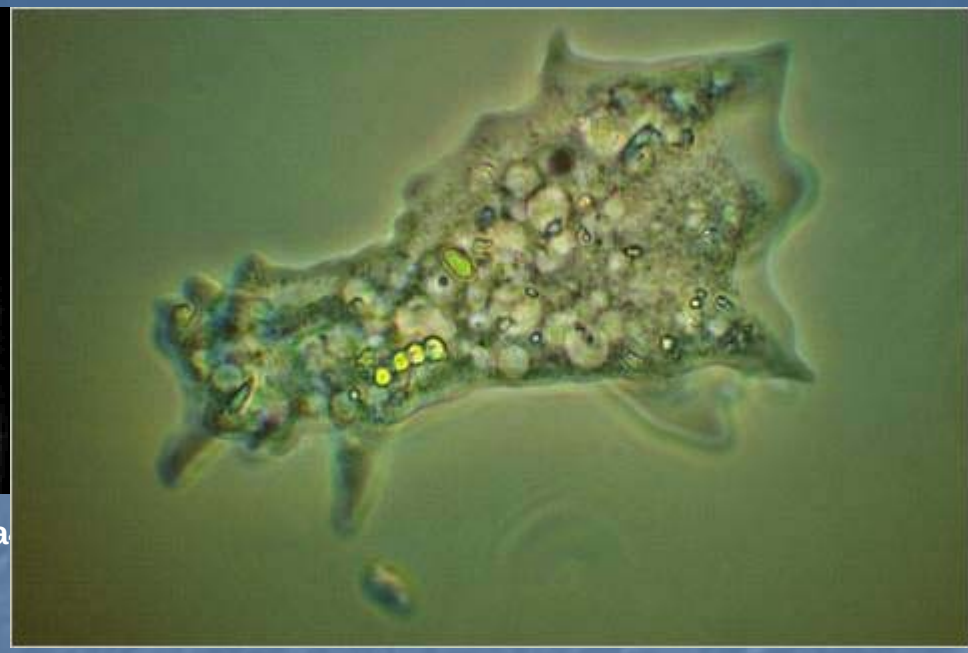
C:N		Arbitrary units of N			% consumed N that is excreted
Prey	Protozoa	Consumption	Production	Excretion	
3	3	33.3	13.3	20	60
5	3	20	13.3	6.7	34
10	3	10	13.3	N deficient	–
3	5	33.3	8	25.3	76
5	5	20	8	12	60
10	5	10	8	2	20
3	10	33.3	4	29.3	88
5	10	20	4	16	80
10	10	10	4	6	60

Amoebae

- Principal consumers of bacteria in soil
  - Regulate population size and composition
  - Accelerate turnover of soil biomass/OM
  - Maintain plant available N
  - Prevent pathogen establishment
- Food source for fungi, nematodes, others
- Cause disease (trypanosomes) - parasites



http://www.bms.ed.ac.uk/research/others/smaciver/Amoeba



http://www.micrographia.com

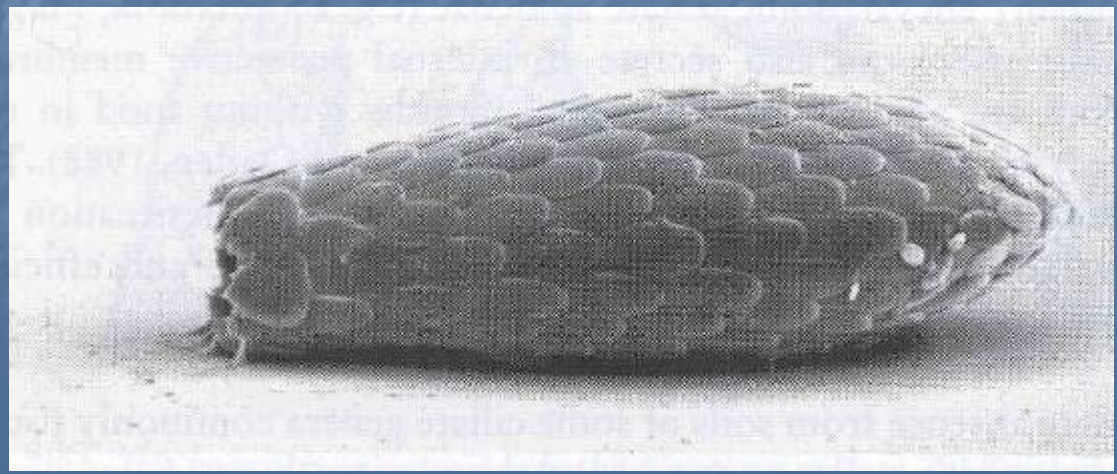
Naked Amoebae

- Motile by means of pseudopodia
- Reproduce by binary fission (like bacteria)
- Phagotrophic
- Fresh water and soil
- *Amoeba and Entamoeba* and slime molds
- Animal parasites (amoeboid dysentery)
- Giant amoeba up to 1 mm diameter

Testate amoebae

- Common in forest soils
- “test” is constructed out of minerals
- Pseudopodia come out the end to feed

www.micrographia.com



Vampyrellid amoebae

- Eat fungi
- Important in the control of soil-borne fungal pathogens
- Puncture hyphae and feed on cellular contents

Rotifer: eating algae

http://www.microscopy-uk.org.uk/mag/imag97/feeder1.jpg

Water Bears: (Tardrigrada)

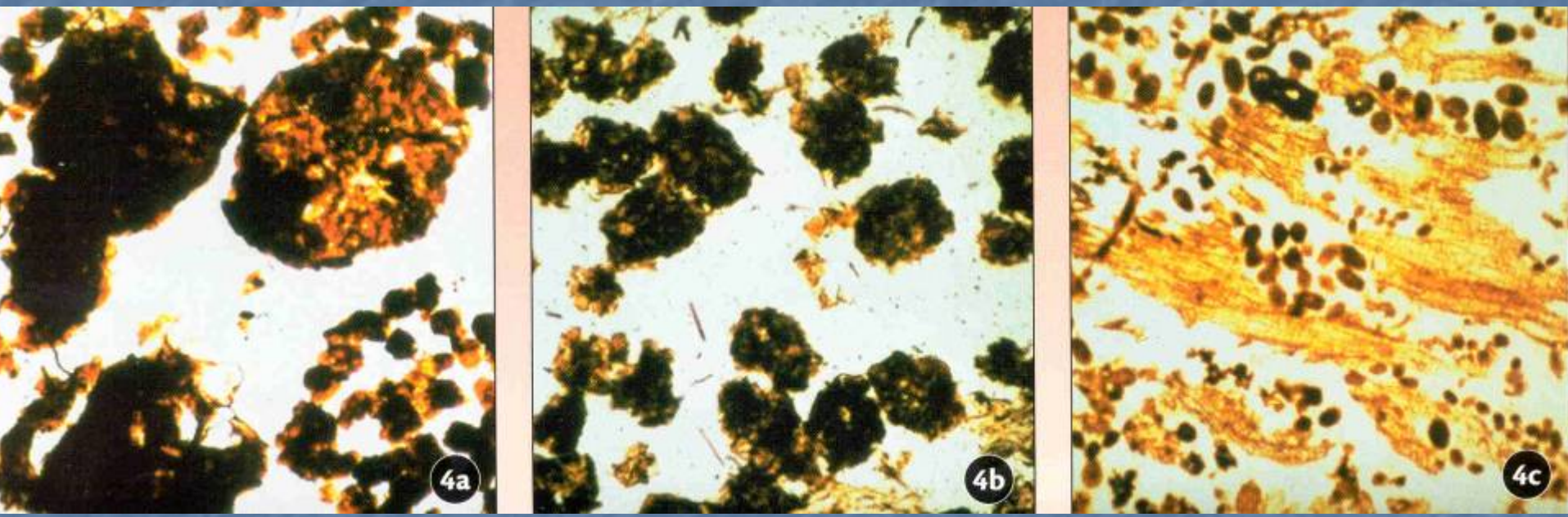
- Feed on algae, fungi, OM, bacteria, plants
- Some prey on nematodes, protozoa
- Preyed upon by amoebae, nematodes, fungi, mites and spiders

Arthropods

Roles of Arthropods in soil

- Shred organic material
- Stimulate microbial activity
- Mix microbes with their food
- Mineralize plant nutrients
- Enhance soil aggregation
- Burrow, increase infiltration
- Control pests
- May also be pests

Frass



Excrement of soil arthropods (frass) provide nutrients for other soil organisms

Springtails (Collembola)

- Fungal and nematode grazing
  - Protect crops from pathogens
- Ubiquitous – 100,000/m^2
- Food source for many predators

Mites (Acari)

- Predators
- Fungal feeders
- Decomposers: shred plant material

D. E. Walter, C. Meacham

R. Norton

A. Hornor

D. E. Walter

Pseudoscorpion

- Top predator of soil food web
- Crytozoans – living under rocks, logs, bark
- Numerous in tropics and subtropics
- Prey on small arthropods, nematodes and enchytraeids

http://www.arachnology.org/

Pot worms (Enchytraeids)

- Anatomically similar to earthworm
- 600 known species
- Decompose plant remains with high microbe populations, earthworm casts, graze on fungal hyphae
- Frass is enriched with nutrients

Earthworms (Annelids)

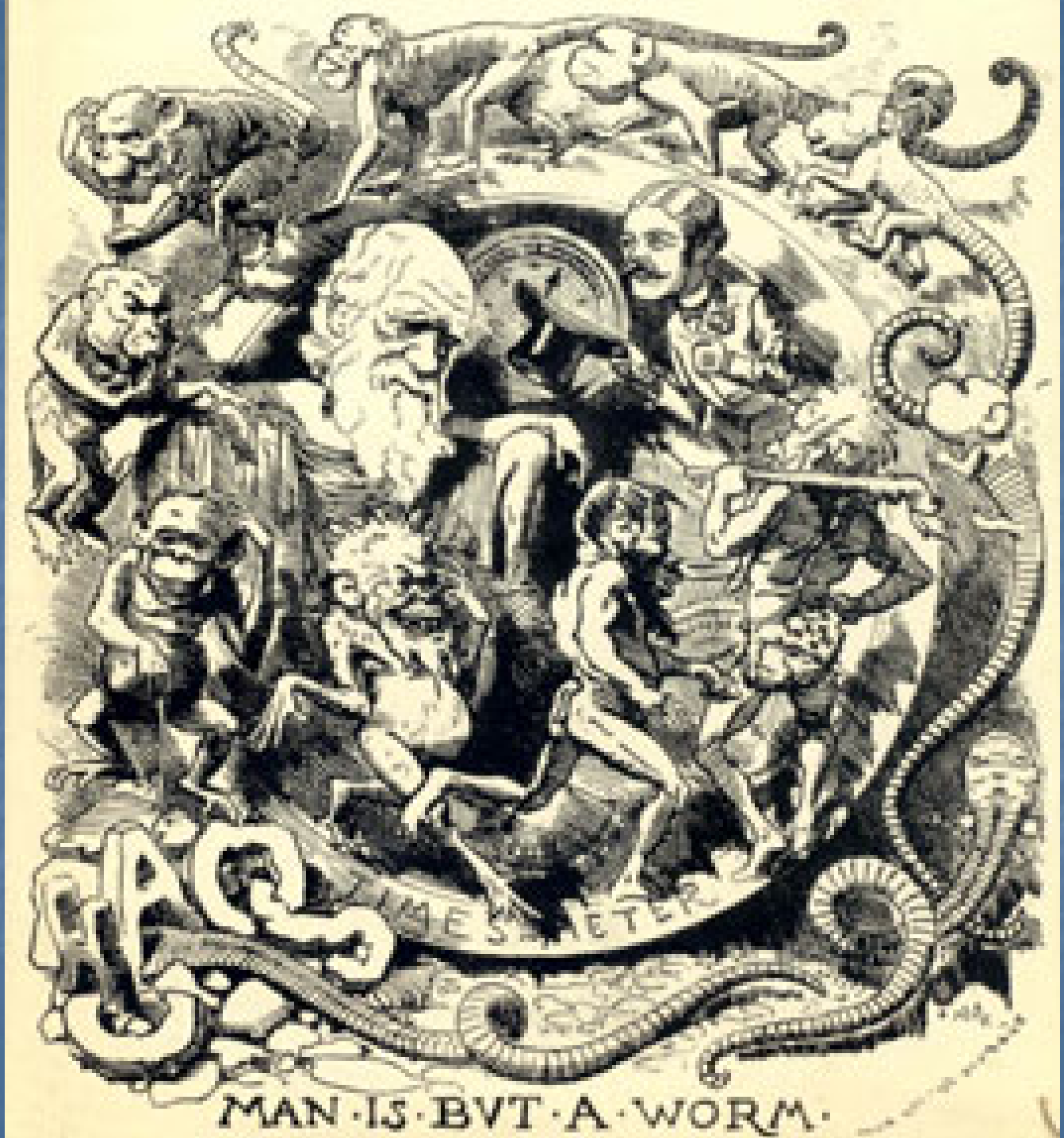
Nightcrawler (Lumbricus terrestris)

Anecic = deep burrowing

Castings

Manure worm a.k.a. Red Wiggler (Eisenia fetida)

Epigeic = surface litter


MAN · IS · BVT · A · WORM ·