LOVE is a BEAUTIFUL THING

Soil Miroorganisms
(why we love microbes)

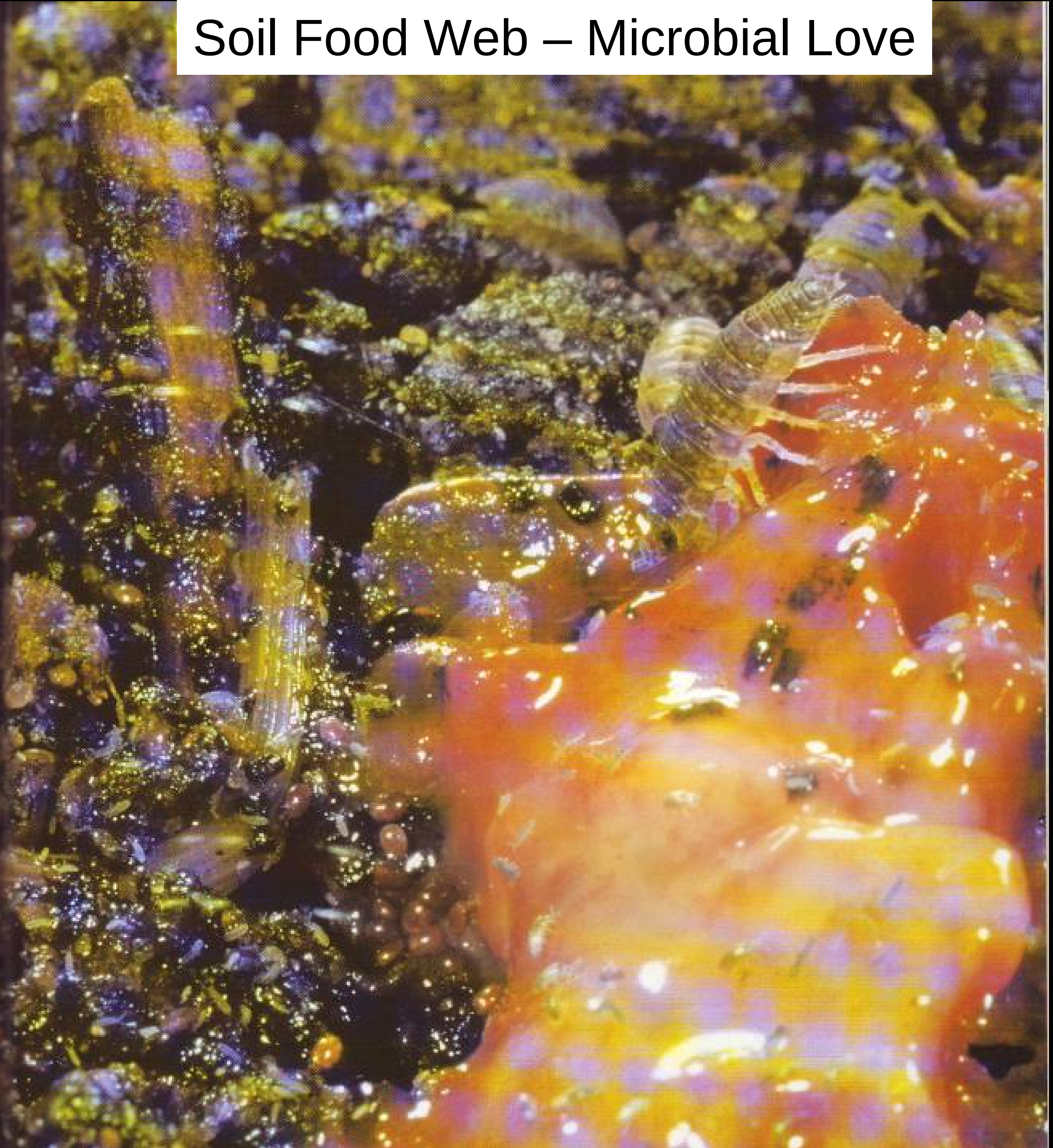
Ecological Agriculture TESC 2-14-06

Steve Scheuerell

Love and Microbes

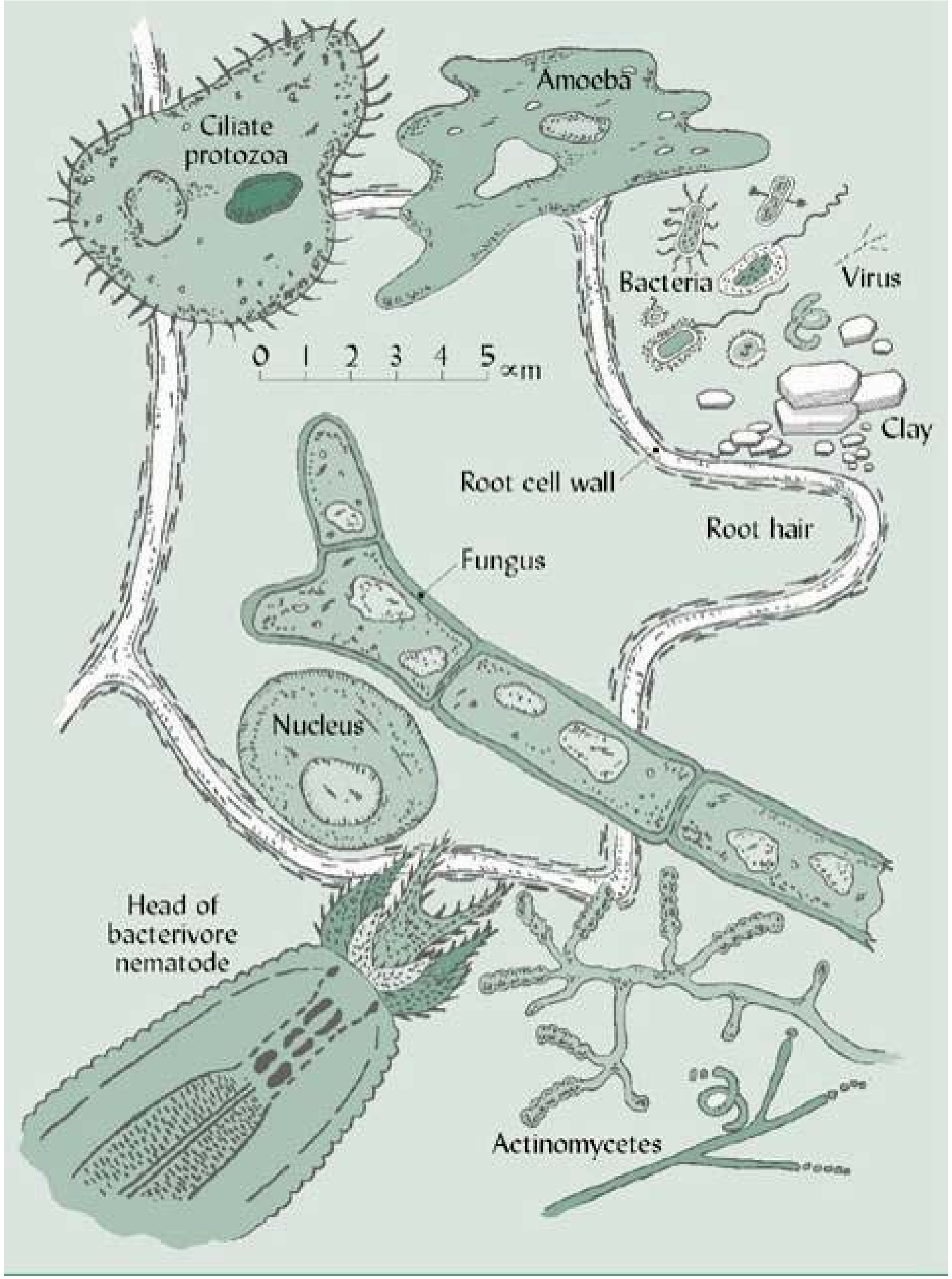
- Halophiles
- Thermophiles
- Mesophiles
- Psychrophiles
- …

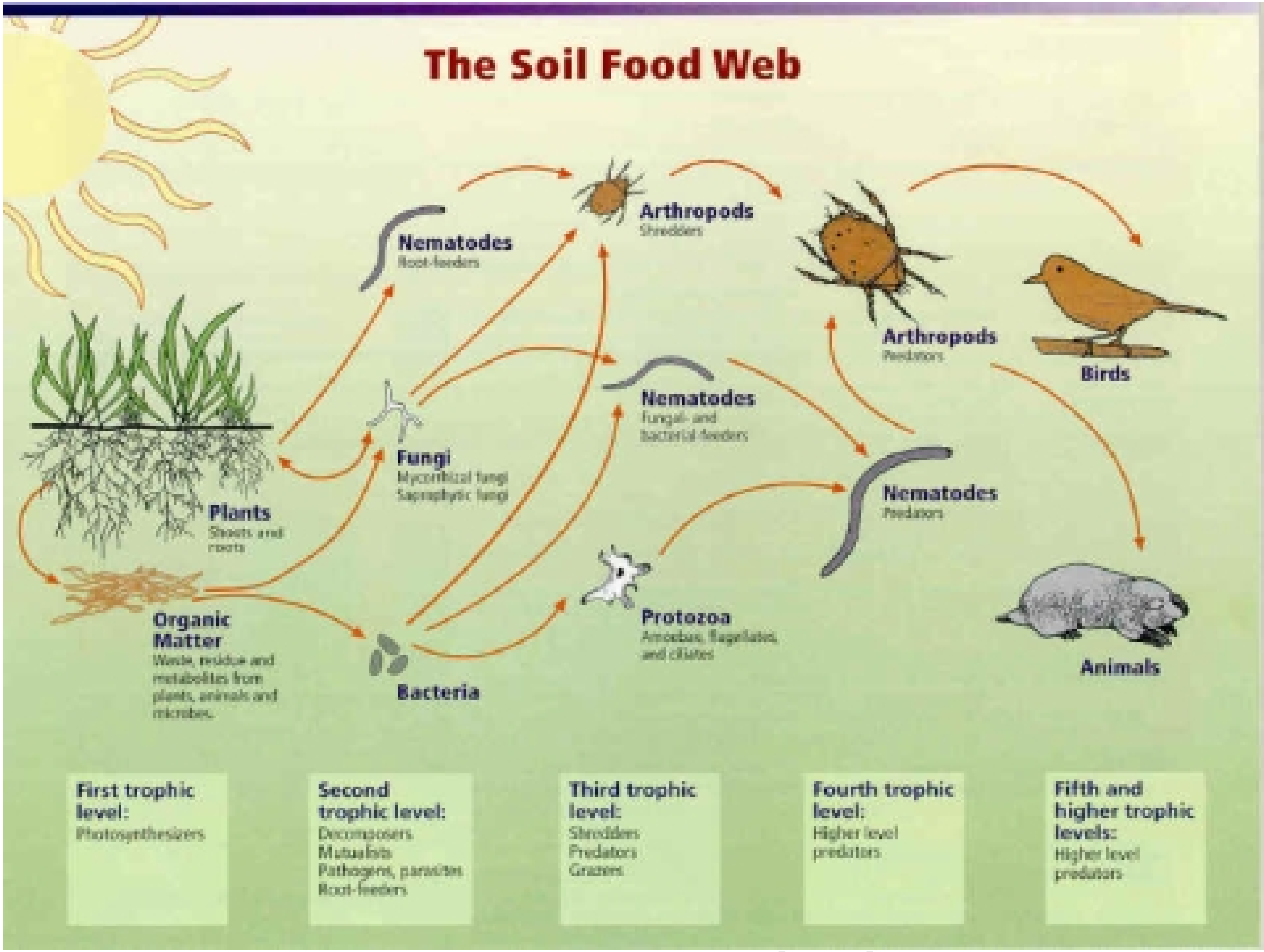
Soil Food Web – Microbial Love



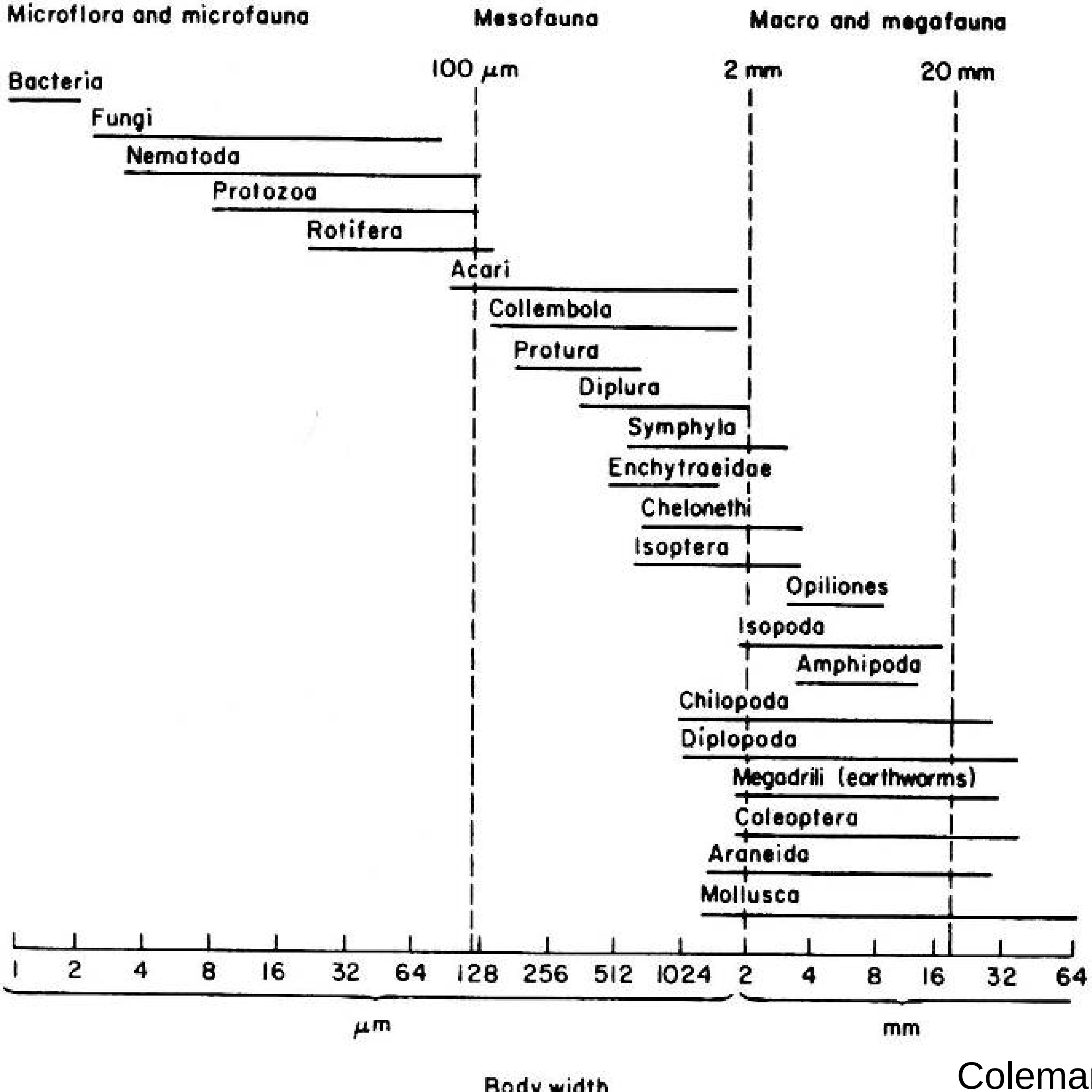
Lavies, 1993

Microbial diversity



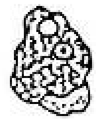
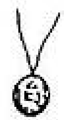
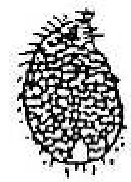
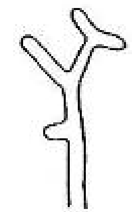
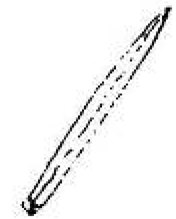


From: *Soil Biology Primer*



Coleman and Crossley, 1996

TABLE 6.2. Average Standing Crop and Energetic Parameters for Microorganisms, Georgia No-Tillage Agroecosystem[a]

	Naked amoebae	*Flagellates*	*Ciliates*	*Bacteria*	*Fungi*	*Microbivorous nematodes*
						
Typical size in soil	30 µm	10 µm	80 µm	0.5–1x 1–2 µm	Ø 2.5 µm 1.0–5.5 µm	Ø ~ 40 µm
Mode of living	In water films on surfaces	Free–swimming in water films		On surfaces	Free and on surfaces	In water films, free, and on surfaces
Biomass (kg dw ha^{1})	95%	5%	<1%	500–750[c]	700–2700[d]	1.5–4[e]
		50[b]				
% active	0–100			15–30	2–10	0–100
Estimated turnover times, season^{-1}		10		2–3	0.75	2–4

Coleman and Crossley, 1996

Biodiversity of Fungi and Bacteria

TABLE 7.2. Comparison of the Numbers of Known and Estimated Total Species Globally of Selected Groups or Organisms[a]

Group	*Known species*	*Estimated total species*	*Percentage known*
Vascular plants	220,000	270,000	81
Bryophytes	17,000	25,000	68
Algae	40,000	60,000	67
Fungi	69,000	1,500,000	5
Bacteria	3,000	30,000	10
Viruses	5,000	130,000	4

[a]From Hawksworth (1991b).

Coleman and Crossley, 1996

Metabolism

- Extremely resistant resting stages
- Rapid reproduction potential in response to food and environment
- In decomposition colonize easy to degrade substrates, especially with tillage
- Ability to use diverse substrates
  - some only catalyzed by bacteria, e.g. nitrifying
- Heterotrophic (parasitic or saprophytic) or Autotrophic
  - Photoautotrophic- energy from sunlight
  - Chemoautotrophic- energy from oxidation of inorganic substrates

TABLE 10.1
Beneficial Functions of Soil Microorganisms in Agricultural Systems

- Release plant nutrients from insoluble inorganic forms
- Decompose organic residues and release nutrients
- Form beneficial soil humus by decomposing organic residues and through synthesis of new
- Produce plant growth-promoting compounds
- Improve plant nutrition through symbiotic relationships
- Transform atmospheric nitrogen into plant-available N
- Improve soil aggregation, aeration, and water infiltration
- Have antagonistic action against insects, plant pathogens, and weeds (biological control)
- Help in pesticide degradation

Kennedy et al, 2004

Bacteria

- "free living" usually attached to a surface
- Symbiotic can be within or on another organism
- Transform, solubilize, mineralize, fix, decompose, base of food chain

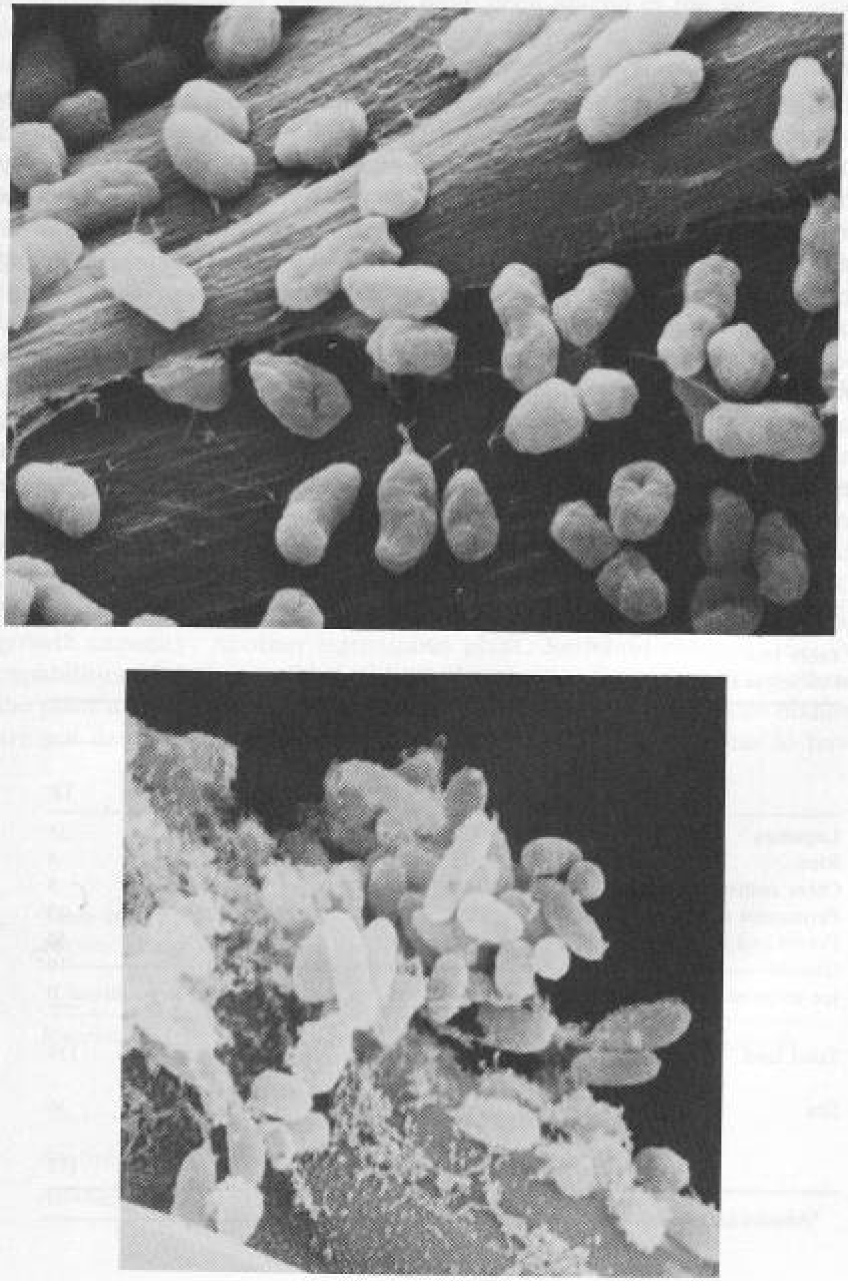
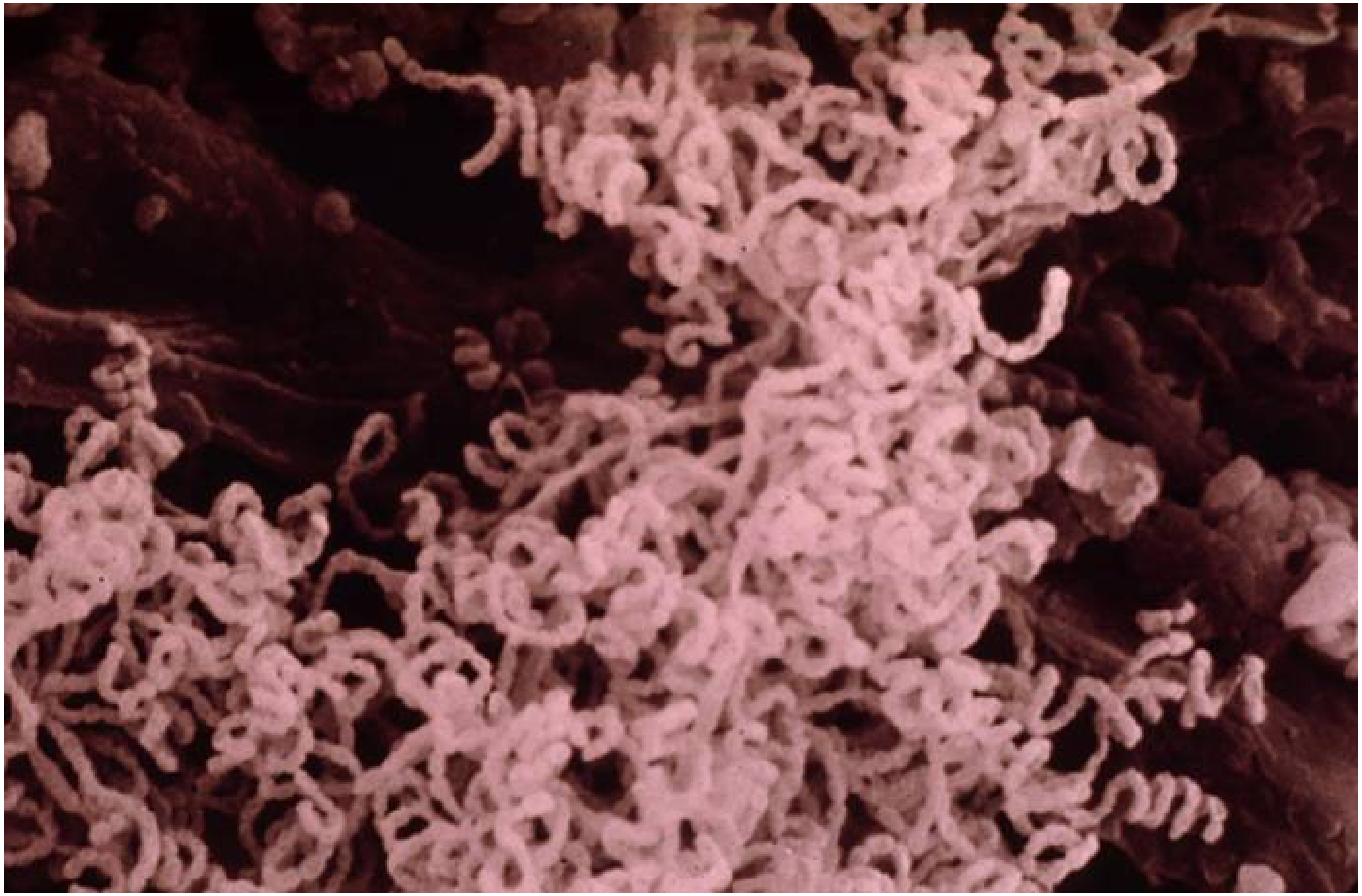


Figure 10.2. Scanning electron micrographs of *Azospirillum brasilense* absorbed to root hairs of maize (top, from Patriquin, 1982) and millet (bottom, photo courtesy of F. Dazzo).

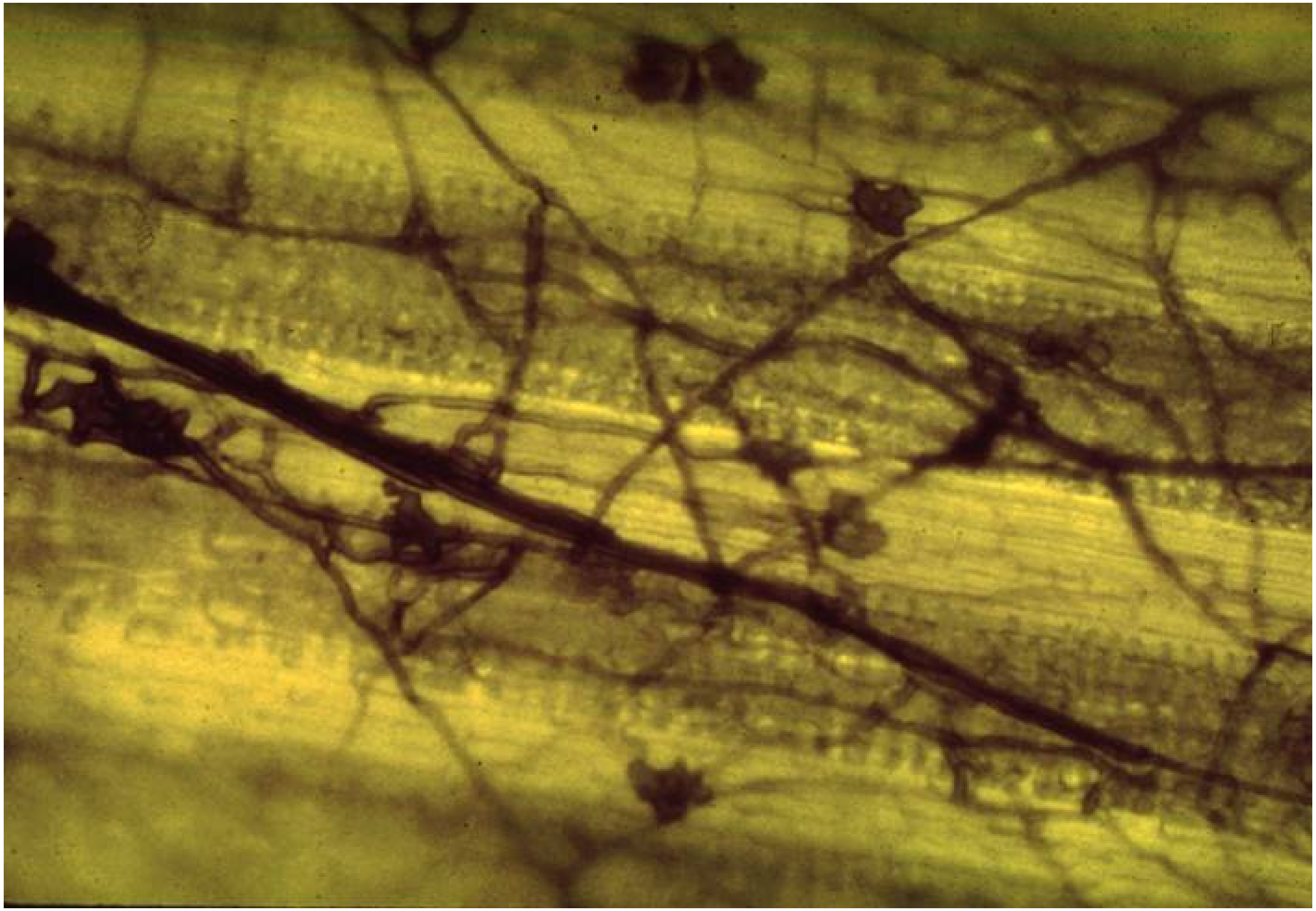
Actinomycetes: Filamentous bacteria



Actinomycetes, such as this *Streptomyces*, give soil and compost its "earthy" smell from *geosmins* a type of terpene.

Soil Microbiology and Biochemistry Slide Set. 1976. J.P. Martin, et al., eds. SSSA, Madison, WI From: *Soil Biology Primer*

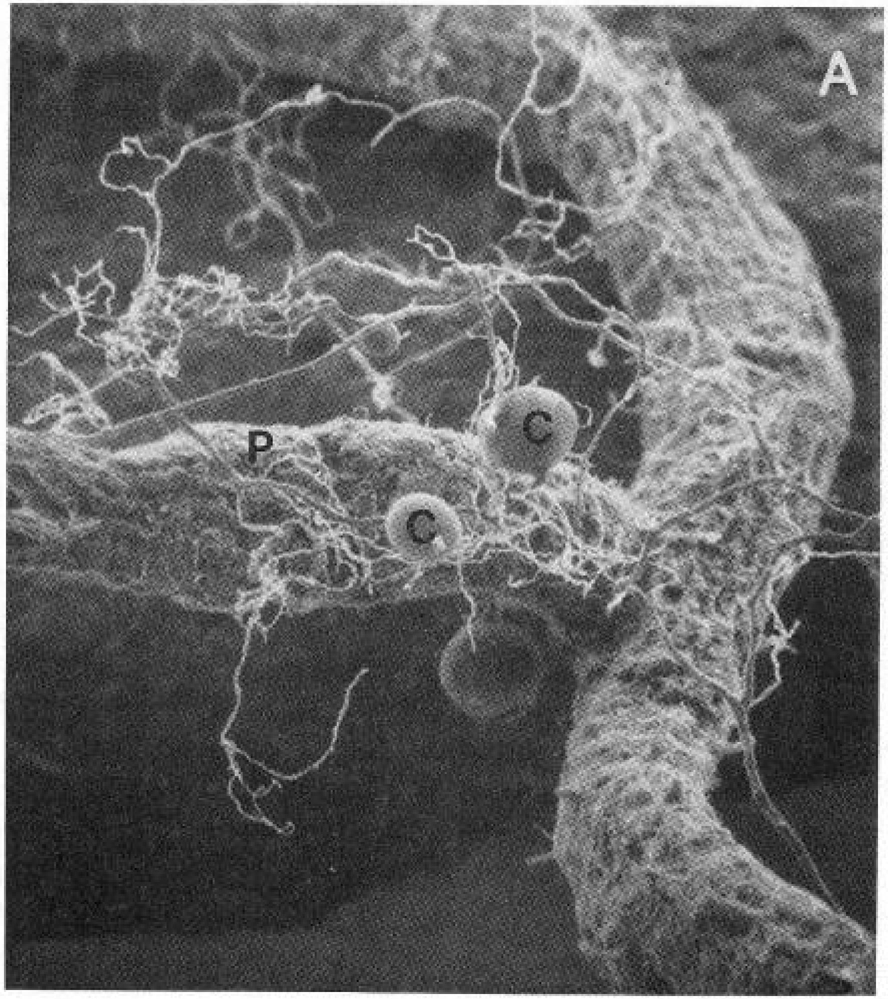
Fungi



Fungus beginning to decompose leaf veins in grass clippings.
Soil Microbiology and Biochemistry Slide Set.
1976. J.P. Martin, et al.,eds. SSSA, Madison WI.

From: *Soil Biology Primer*

Figure 11.4. Scanning electron micrographs of *Glomus* spp. (*A*) Chlamydospores (C) and hyphae (P) of *G. fosciculatus* on a soybean root; (*B*) Sporocarp (S), probably containing a single spore and chlamydospore (C) of *G. mosseae;* (C) Chlamydospore of *G. mosseae*, showing the funnel-shaped subtending hypha (arrow). (From Brown and King, 1982.)



Fungal hyphae and resting spores - Chlamydospores

Paul and Clark, 1989

Biological control of plant pathogenic fungi by
- antibiosis
- parasitism

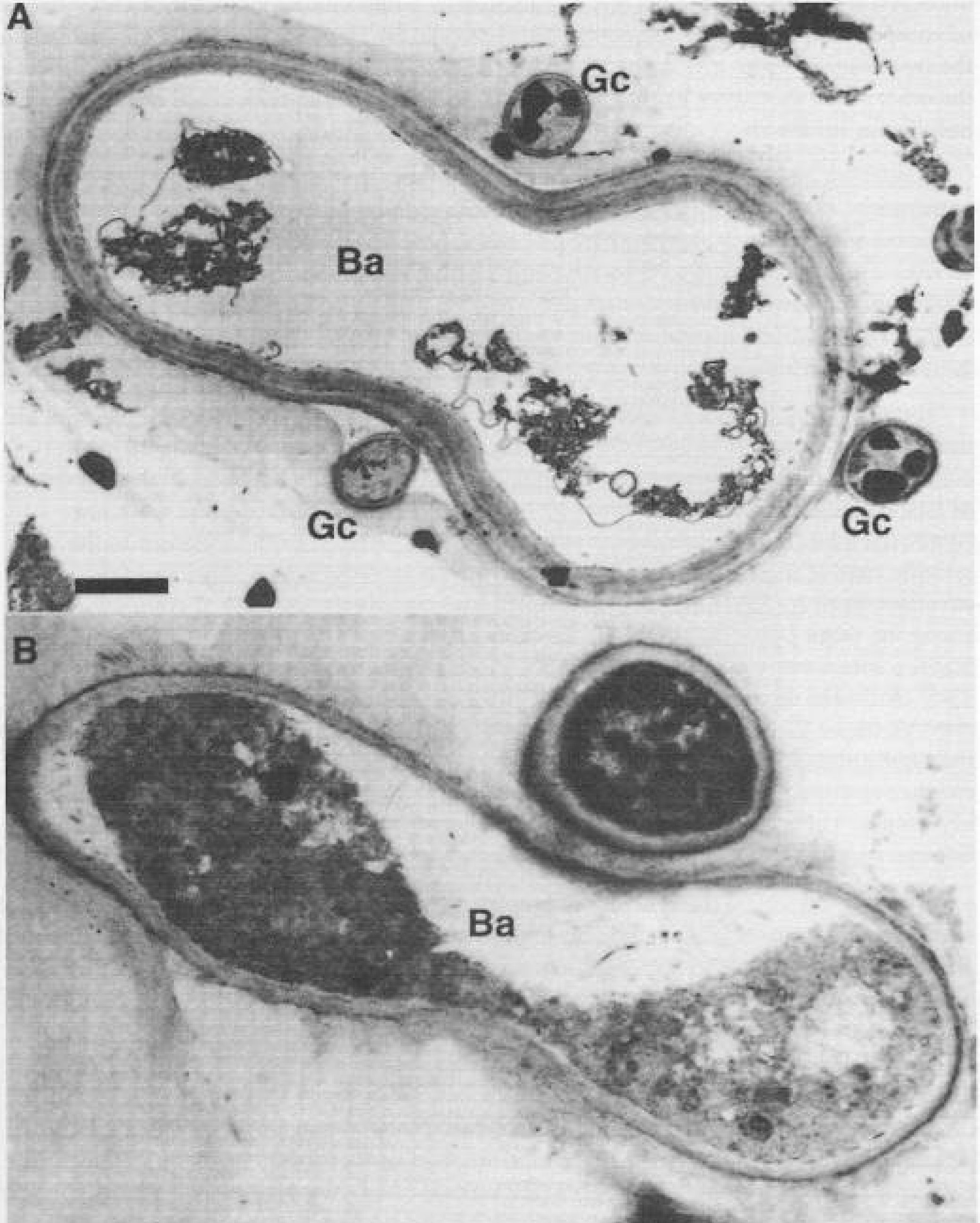


Fig. 2. Electron micrographs of **A.** a dead cell of *Botrytis aclada* (Ba) surrounded by three cells of *Gliocladium catenulatum* (Gc) (bar = 2 μm) and **B.** a cell of Ba in contact with *Aureobasium pullulans* (Ap) (bar = 1 μm).

Belanger and Avis, 2004

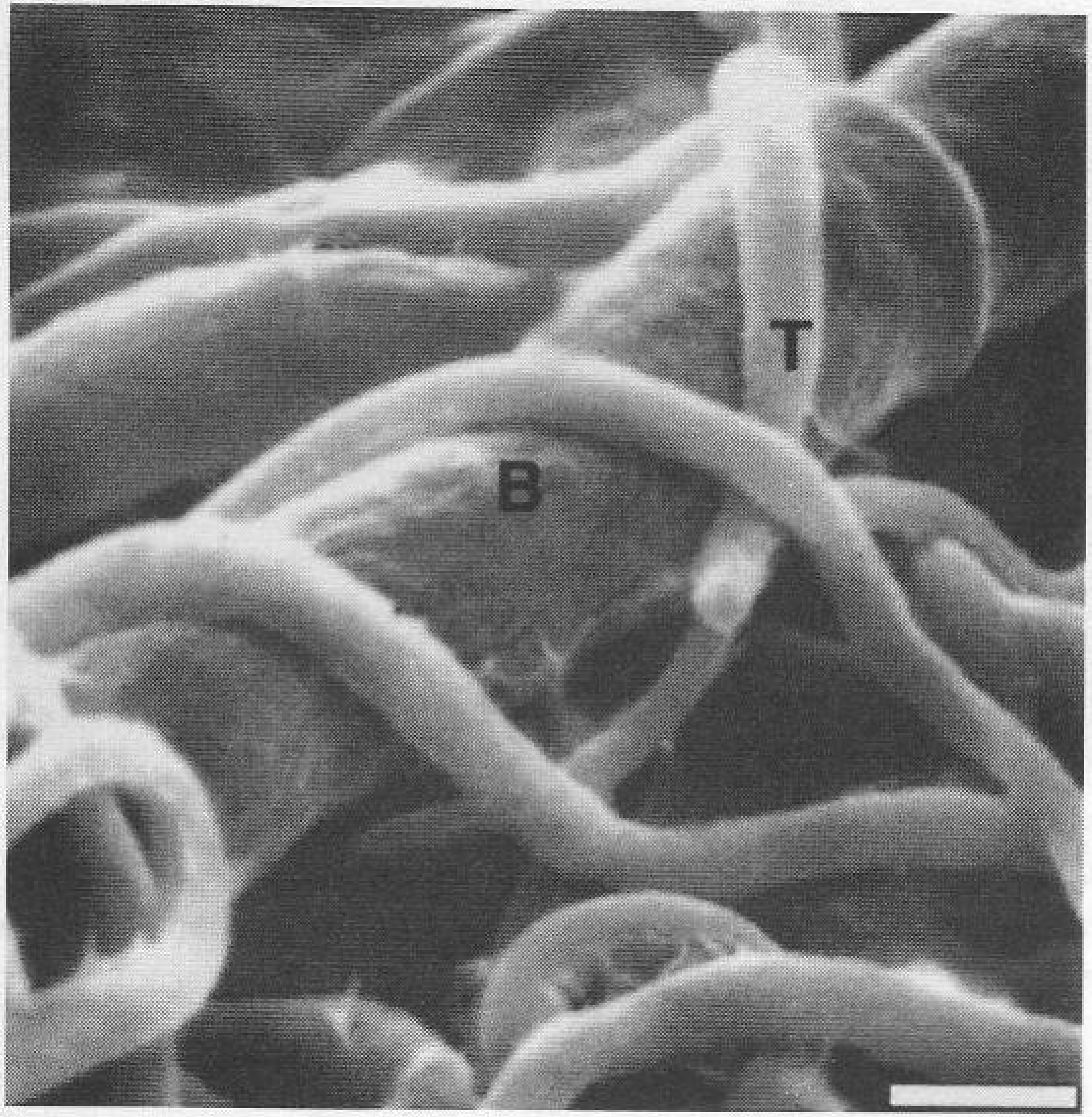
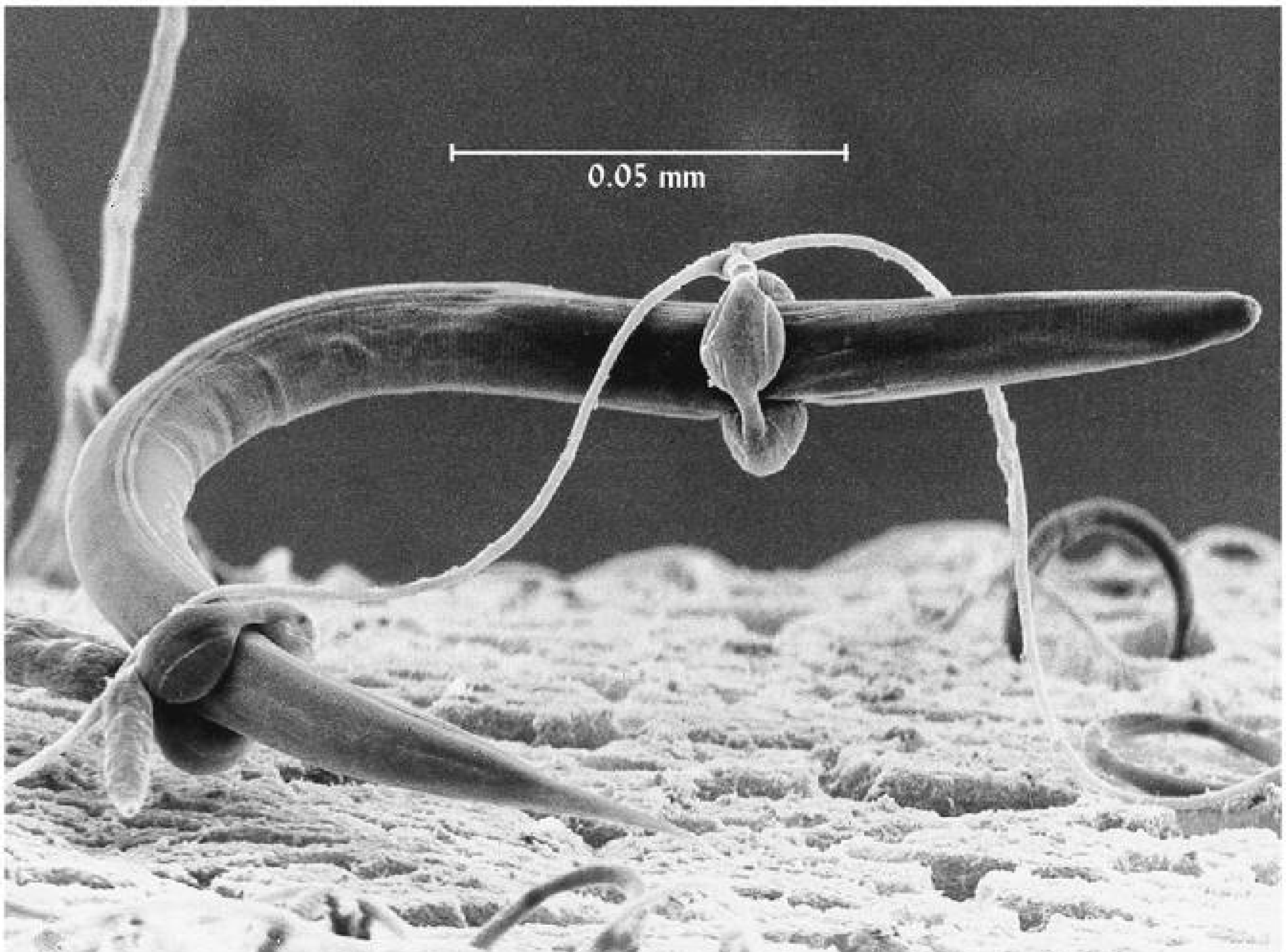


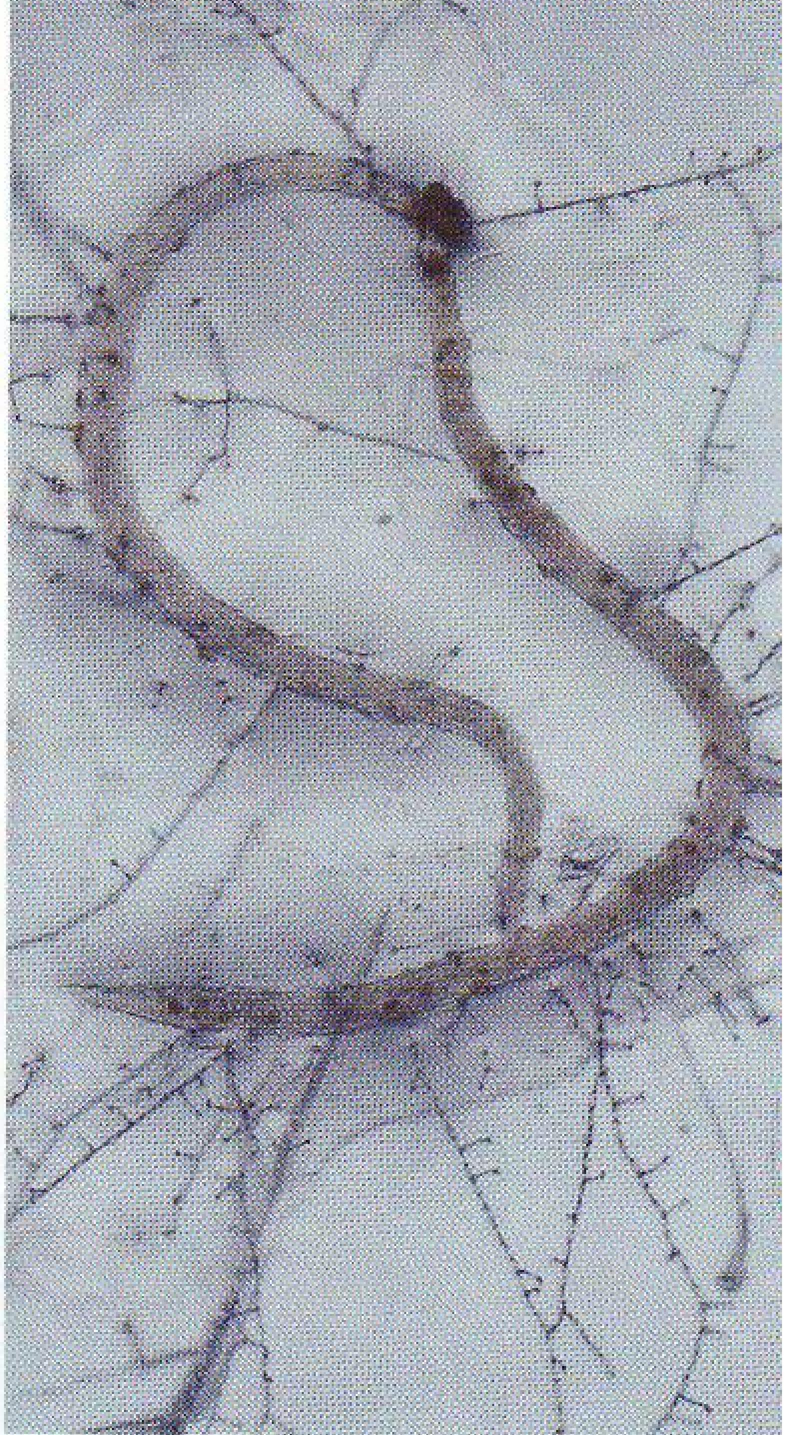
Fig. 3. Scanning electron micrographs of the interaction between hyphae of *Trichoderma harzianum* (T) and *Botrytis cinerea* (B). Bar = 4 μm.

Belanger and Avis, 2004

Fungal cells that swell and contract around the nematode



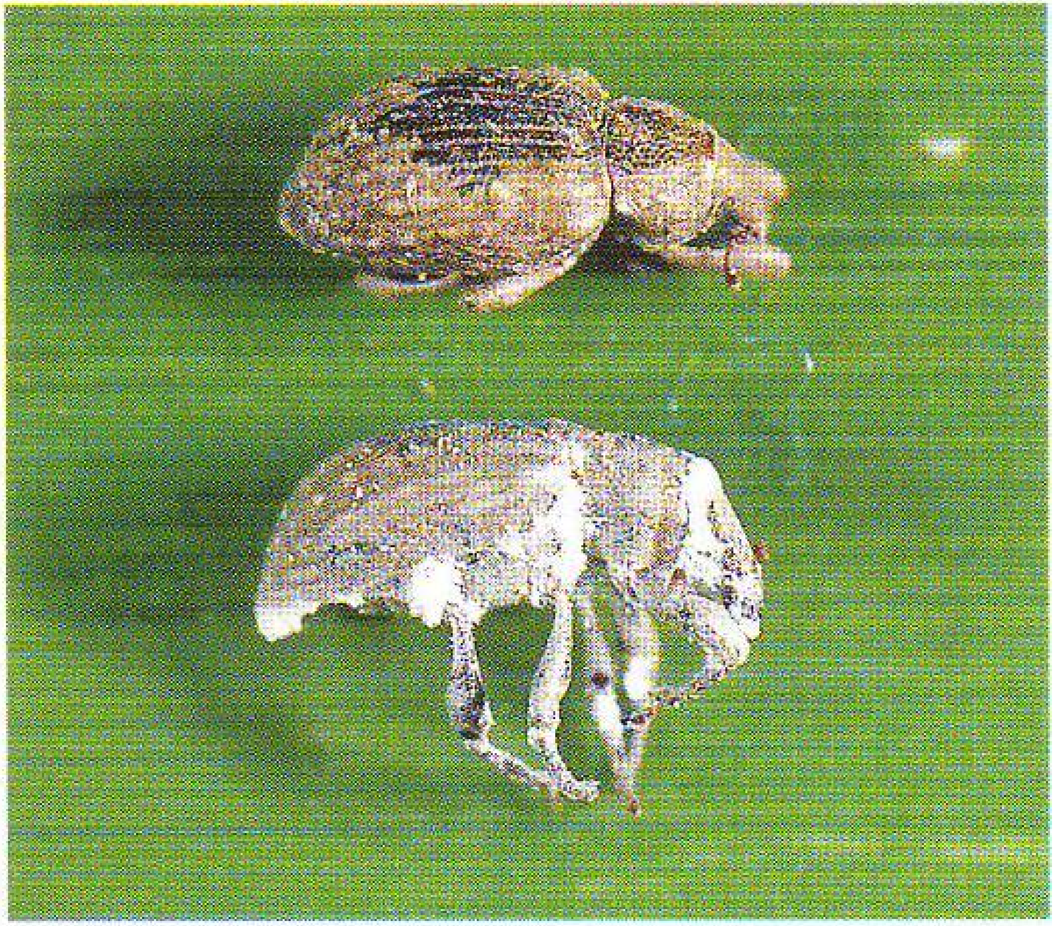
BW Ch 11 Fig 11.22



Fungal parasitism of nematodes

Flint and Dreistadt, 1998

Fungal parasitism of weevils



LENGTH

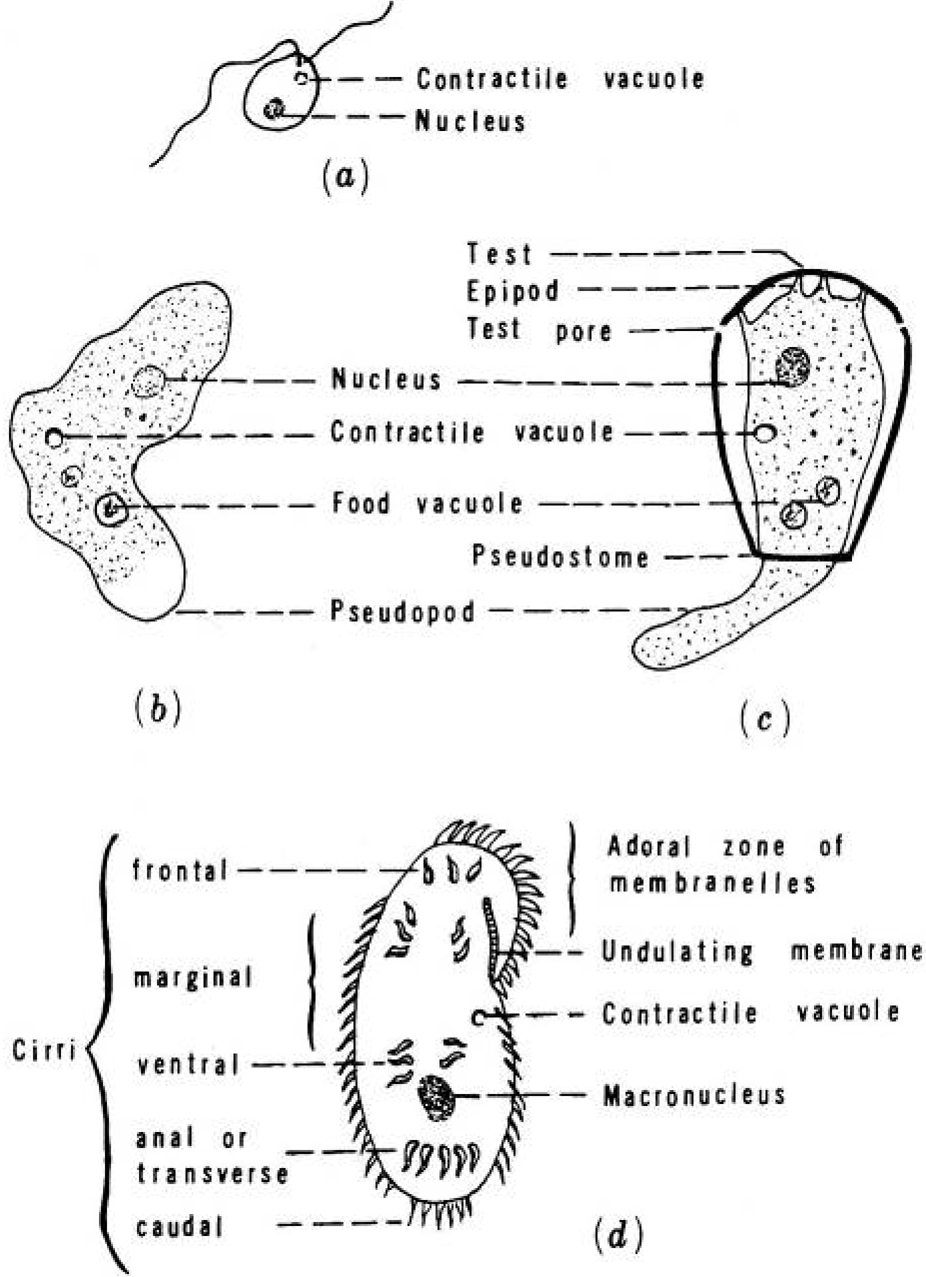
Beauveria bassiana killed the rice water weevil shown here at the bottom and covered its body with whitish fungal mycelia.

Flint and Dreistadt, 1998

Protozoa

- Single celled that capture and engulf their food
- Larger than bacteria
- Three groups: Amoebas, ciliates, flagellates
- 10,000-100,000 individual per gram
- 20-200 kg.ha
- Most prey on bacteria and can influence nitrogen availability like nematodes
- Found in rhizosphere

Protozoa



Coleman and Crossley, 1996

FIGURE 4.4 Morphology of four types of soil Protozoa: (a) flagellate (*Bodo*), (b) naked amoeba (*Naegleria*), (c) testacean (*Hyalosphenia*), and (d) ciliate (*Oxytricha*) (from Lousier and Bamforth, 1990).

Nematode head structures indicate trophic group

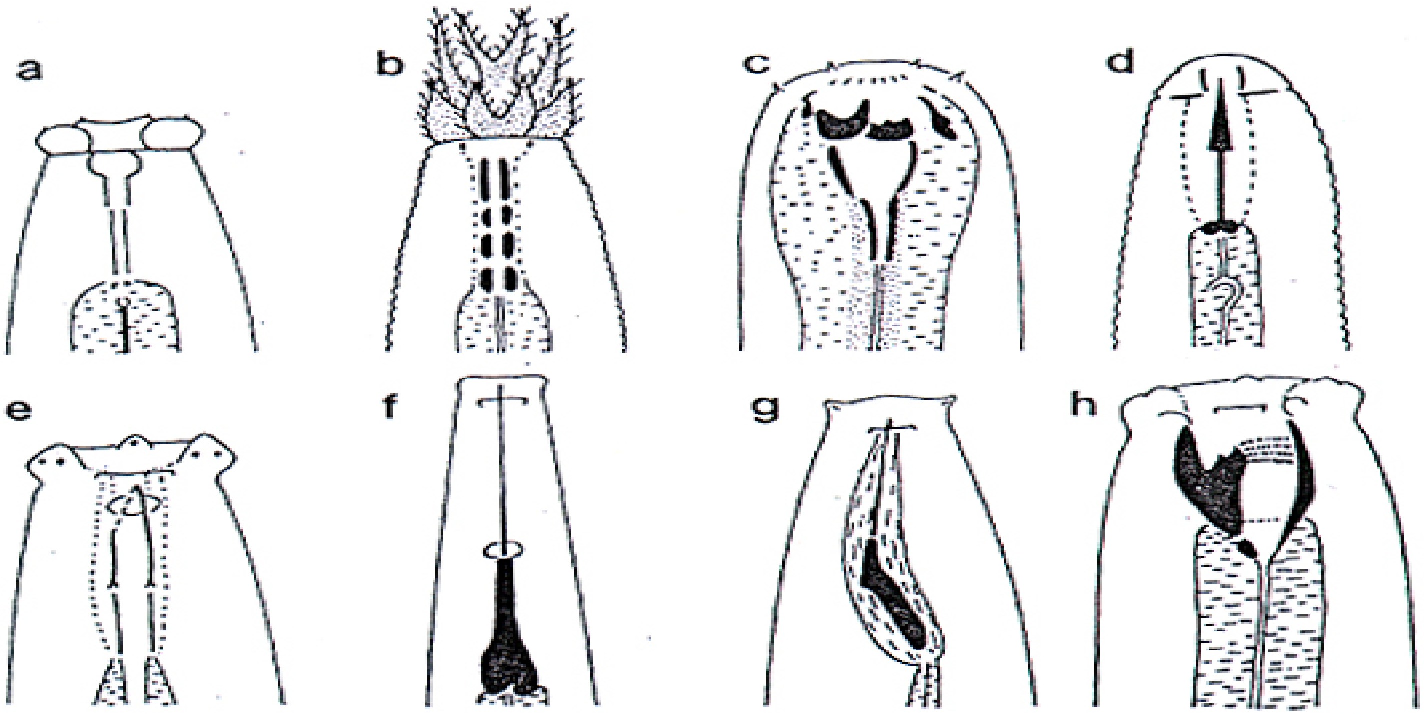


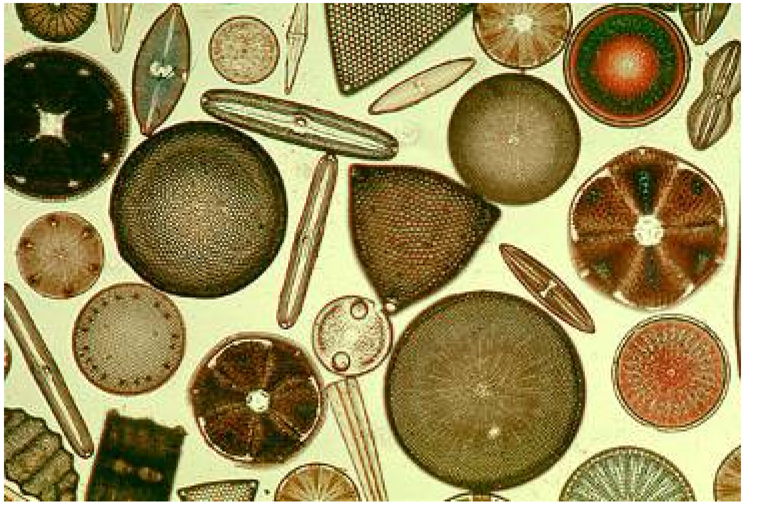
FIGURE 4.7 Head structures of a range of soil nematodes. (a) *Rhabditis* (bacterial feeding); (b) *Acrobeles* (bacterial feeding); (c) *Diplogaster* (bacterial feeding, predator); (d) tylenchid (plant feeding, fungal feeding, predator); (e) *Dorylaimus* (feeding poorly known, omnivore); (f) *Xiphinema* (plant feeding); (g) *Trichodorus* (plant feeding); (h) *Mononchus* (predator). [Reprinted from Yeates, G. W., and Coleman, D. C. (1982). Role of nematodes in decomposition. *In* "Nematodes in Soil Ecosystems" (D. W. Freckman, ed.), pp.55–80. Courtesy of the University of Texas Press, Austin.]

Nematodes

RKN of bean

- Predatory in general
  - bacteria, fungi algae, protozoa, other nematodes and insect larvae (biological control of corn rootworm)
- Release nutrients from feeding on bacteria and fungi
  - bacteria contain more N than nematodes need
  - can account for 30-40% of N released
- Beneficial but some plant parasitic

Algae

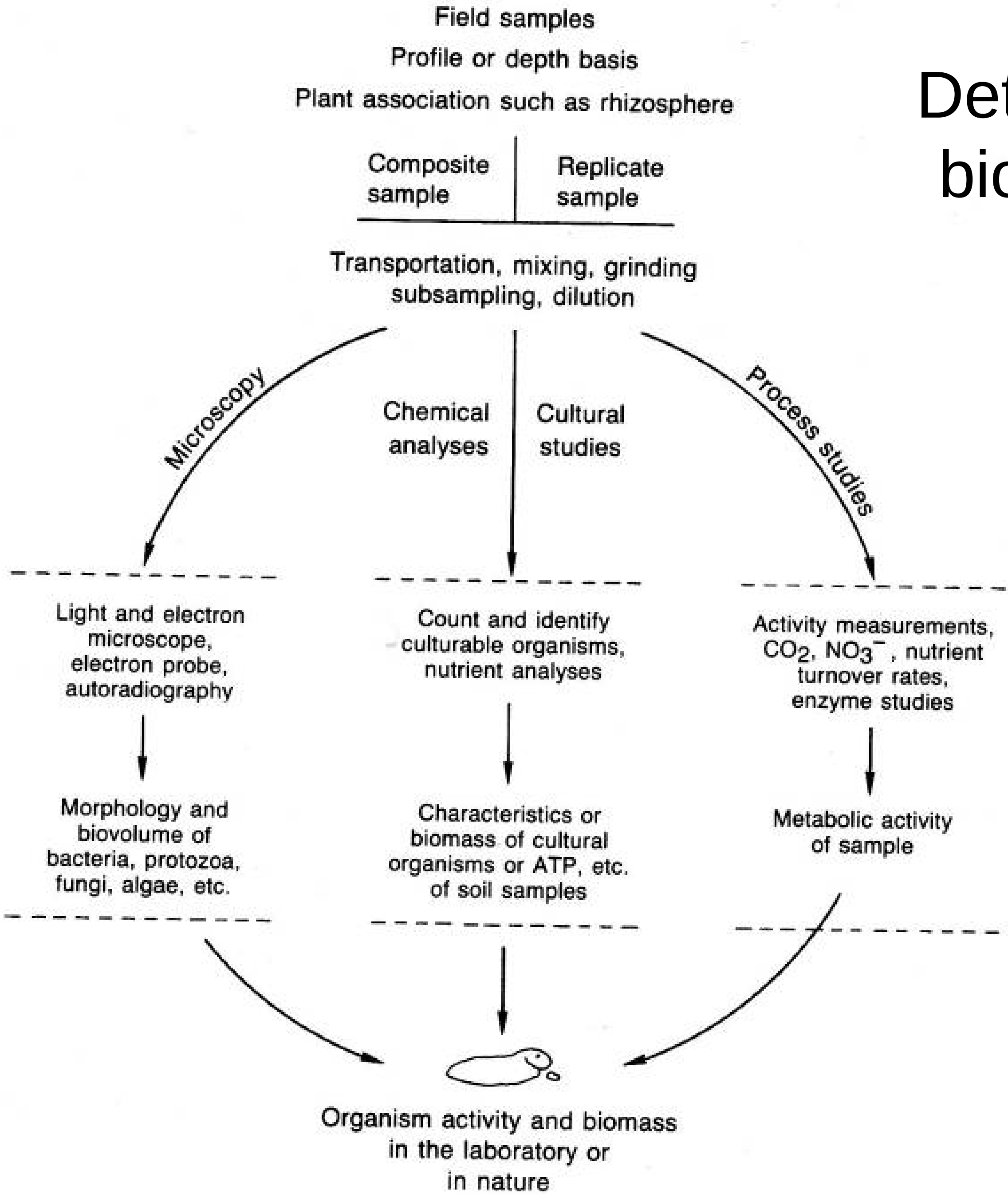


Diatoms, one type of soil algae

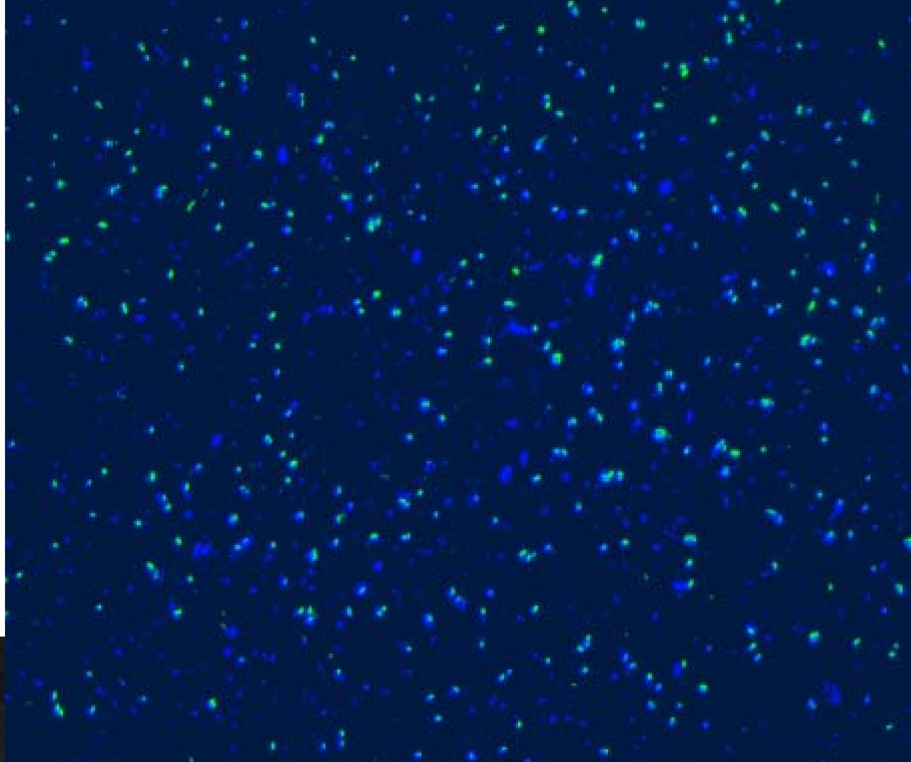
- 1 to 10 billion per m^2
  or 10,000 to 100,000/g
- 10 - 500 kg/ha
- Are eukarotes (nuclear membrane)
- Photosynthesize, so found on surface of soil
- Produce OM, polysaccharides
- Important form mat on soil surface, microbiotic crusts in desert and lichens (with fungi)

Determining microbial biomass and activity

Figure 3.1. Methods for determining microbial biomass and activity.



Paul and Clark, 1989



<u>Microbial Populations</u>

Direct Microscopy

Active Bacterial Cells = Green

Total Bacterial Cells = Blue

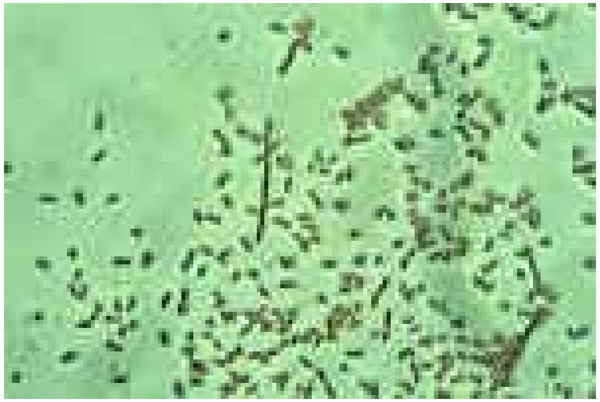
Culturable Populations

Plate Counts

Colony forming units (CFU)

Most bacteria (99%) cannot be cultured

- How do we know?
  - Direct counts and genetic diversity (DNA assessment)



A ton of microscopic bacteria may be active in each acre of soil.

Bacteria dot the surface of strands of fungal hyphae.

From: *Soil Biology Primer*

Decomposition of Organic Matter

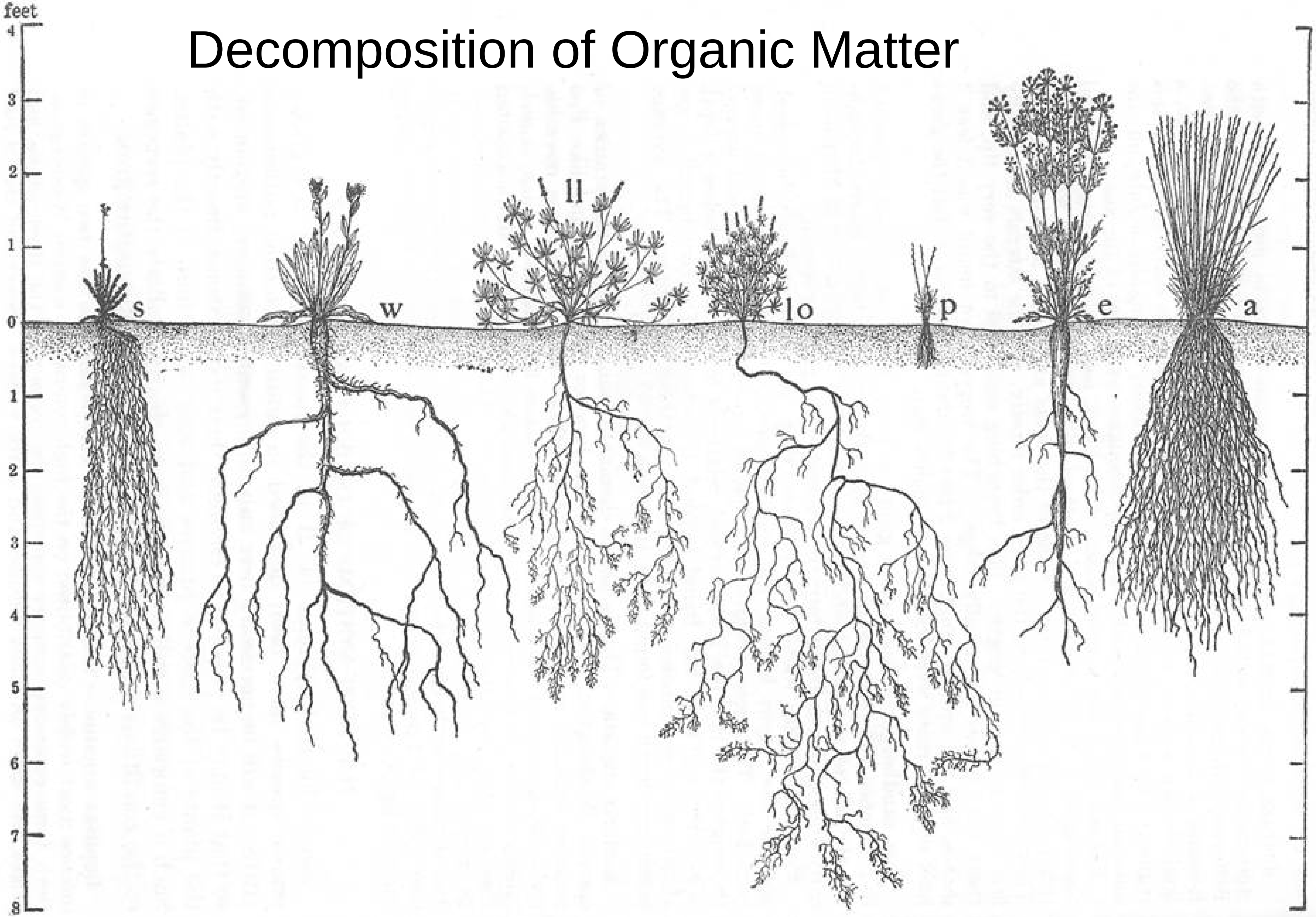


FIG. 7.—Schematic bisect: *s*, *Sieversia ciliata*; *w*, *Wyethia amplexicaulis*; *ll*, *Lupinus leucophyllus*; *lo*, *Lupinus ornatus*; *p*, *Poa sandbergii*; *e*, *Leptotænia multifida*; *a*, *Agropyrum spicatum*.

Weaver, 1919

Kennedy et al, 2004

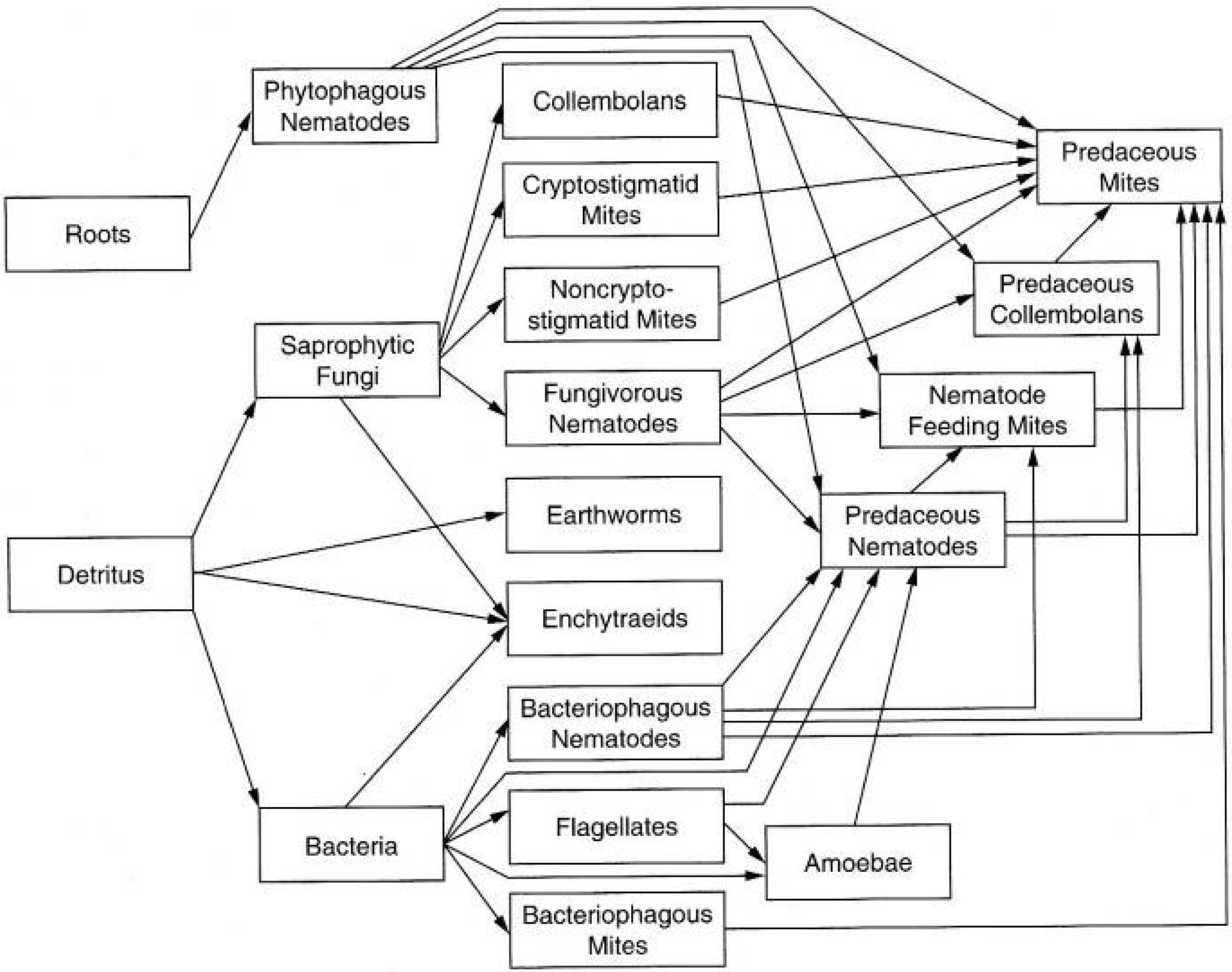
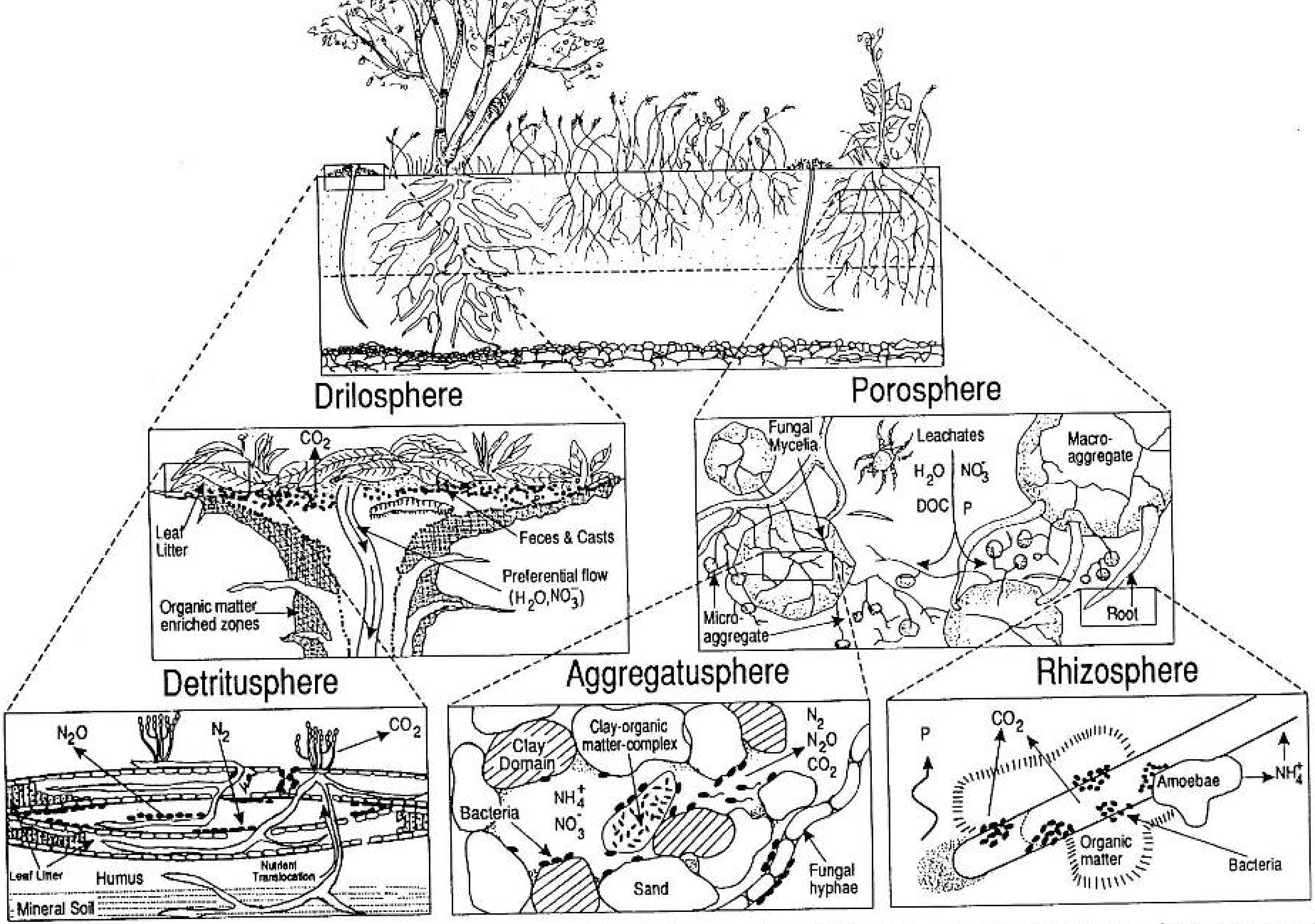
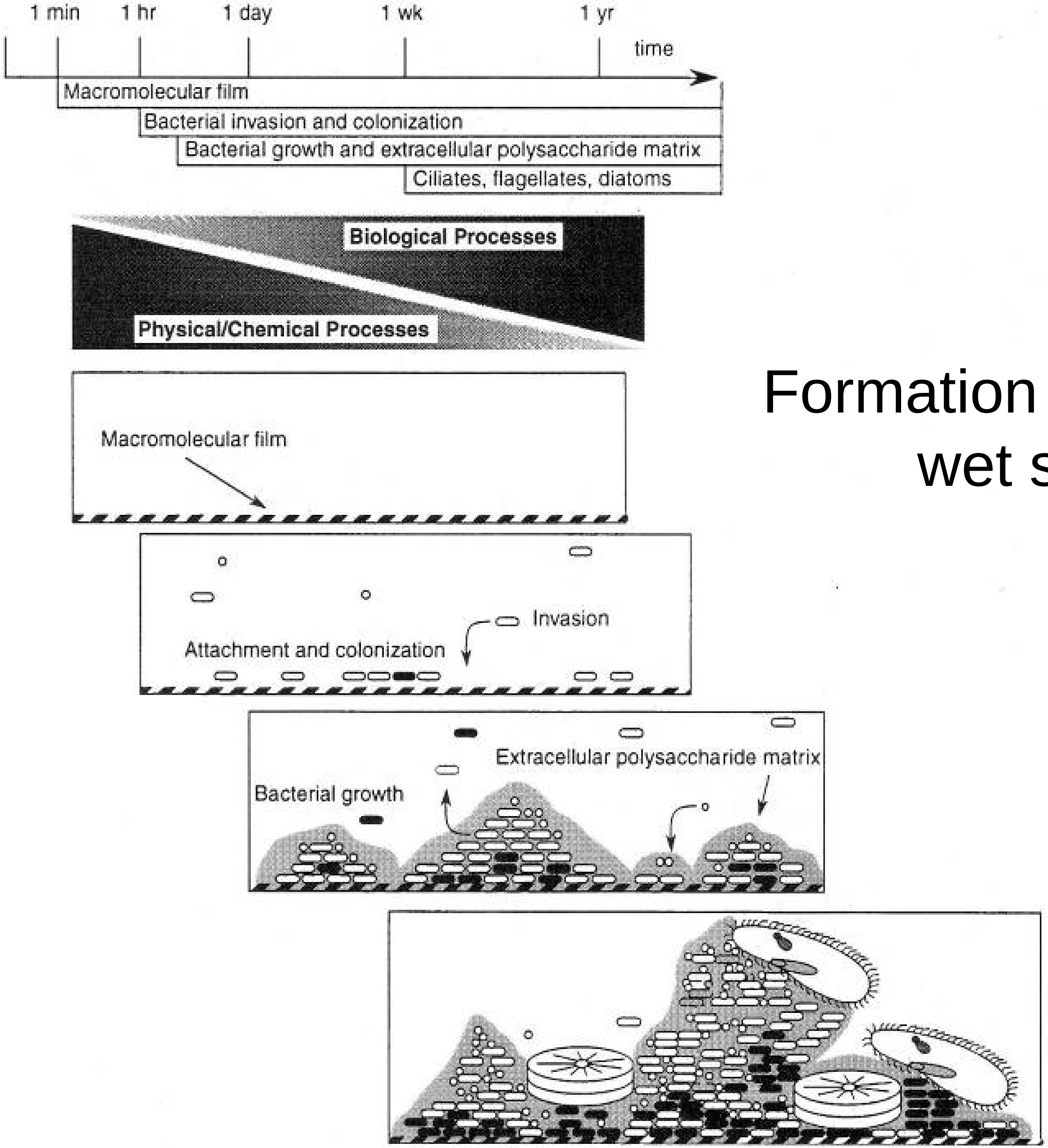


FIGURE 7.6 Soil food web from a farm in which >50% of nitrogen was provided by manure application. Although soil invertebrates contribute relatively little to soil biomass and respiration, this diagram illustrates the variety of ecological boxes that they fill. (From De Ruiter, P.C. et al. 1993. *J. Appl. Ecol.* 30: 95–106. With permission.)



Coleman and Crossley, 1996

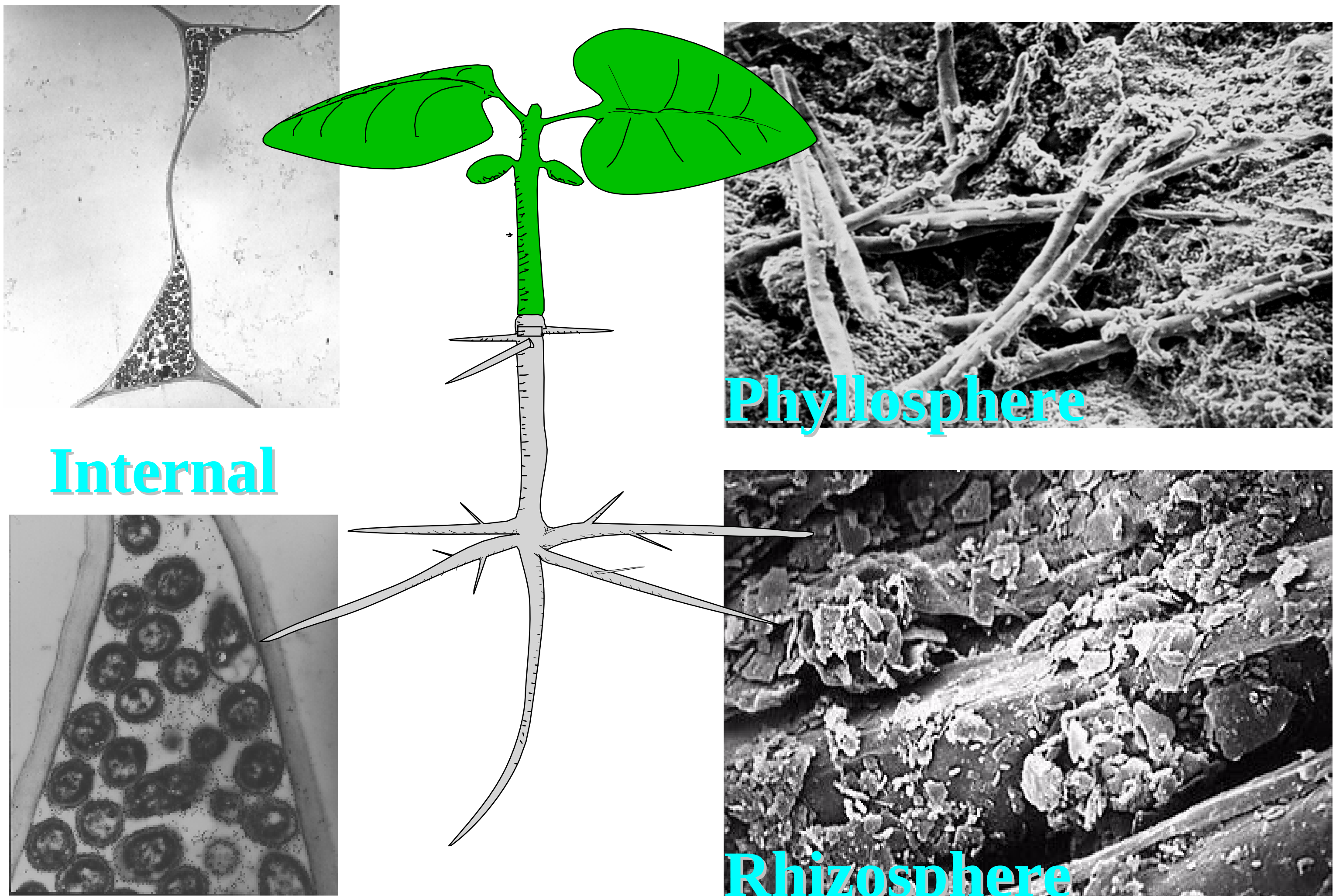
Colonization by microbes



Formation of biofilms on wet surfaces

Atlas and Bartha, 1996

Microbial Habitats of Plants



Kennedy et al, 2004

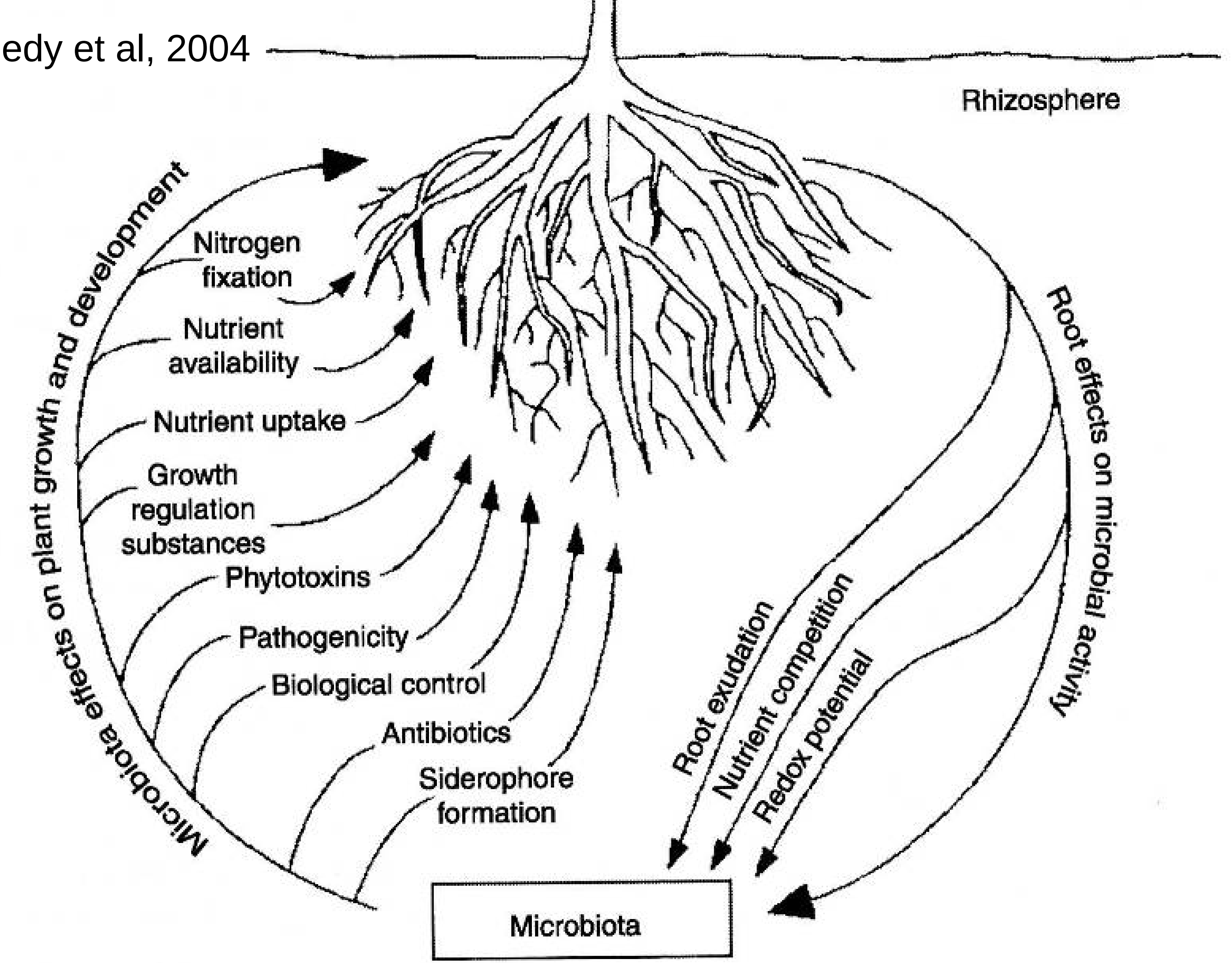
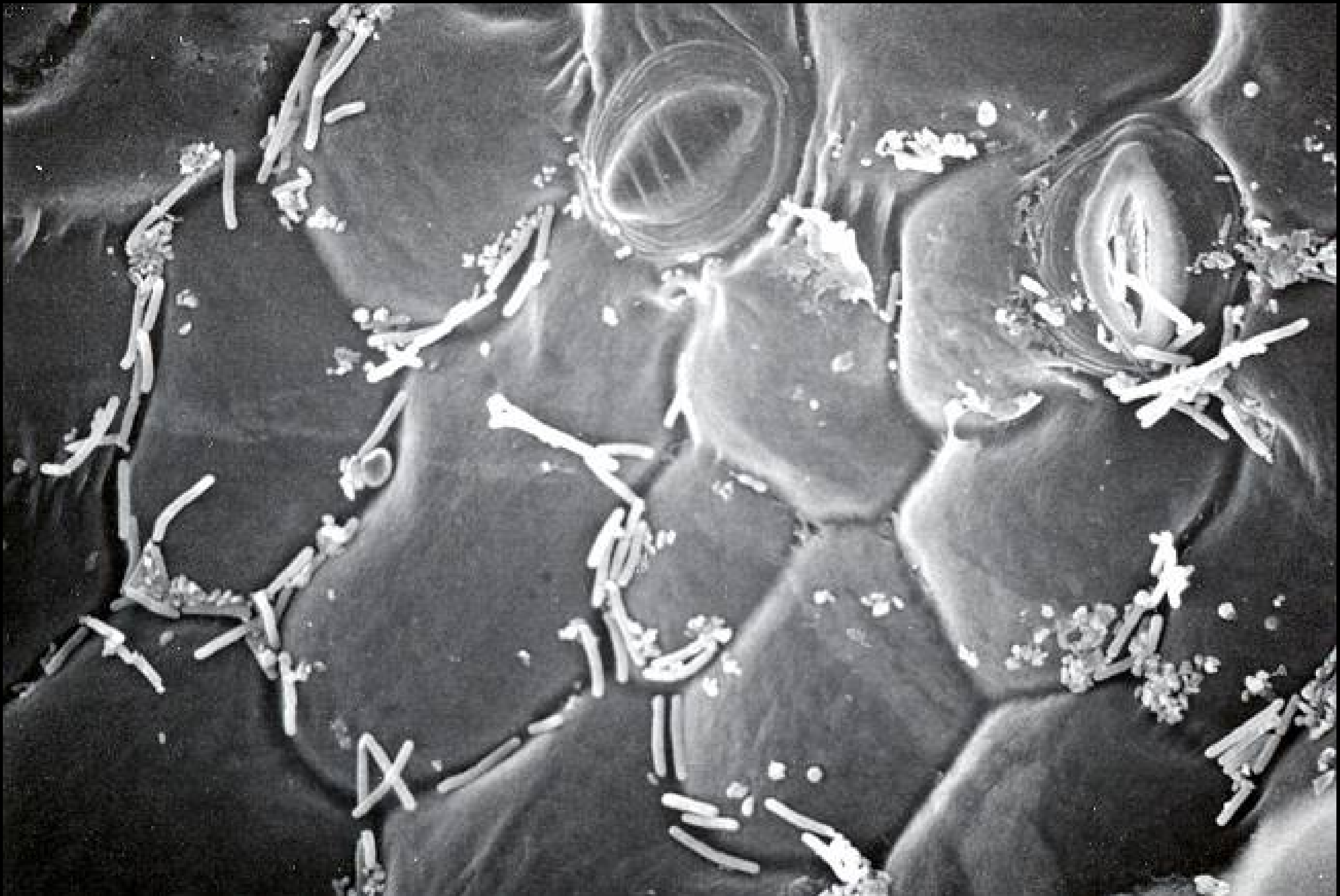
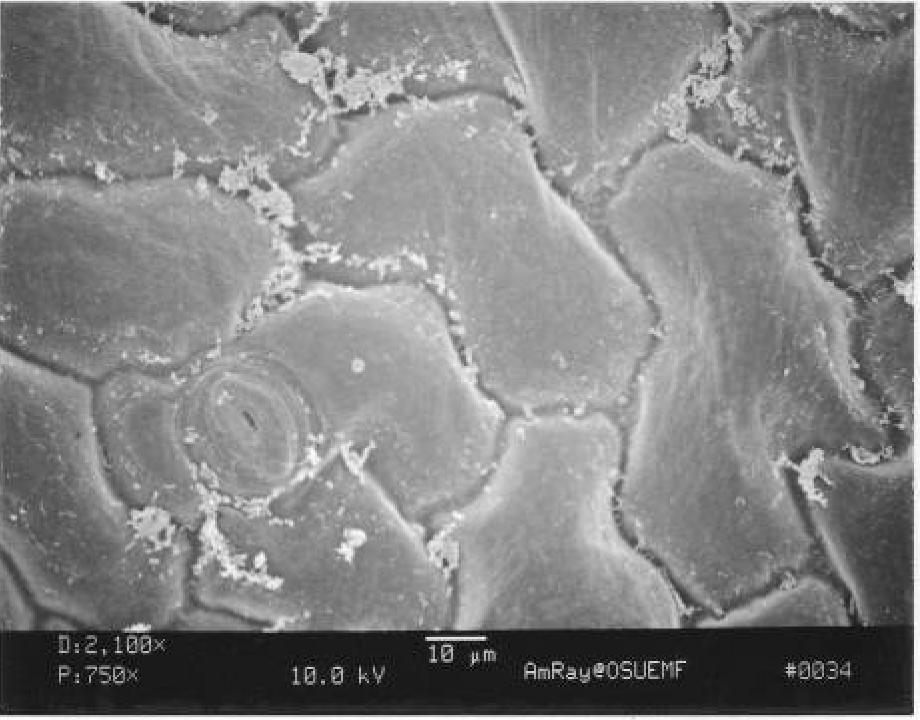


FIGURE 10.4 Plant–microbe interactions affecting plant growth. (From Frankenberger, W.T., Jr., and M. Arshad. 1995. *Phytohormones in Soils: Microbial Production and Function*. Marcel Dekker, New York, 503 pp. With permission.)

Leaf Surface Bacteria - Epiphytes

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10 µm
AmRay@OSUEMF
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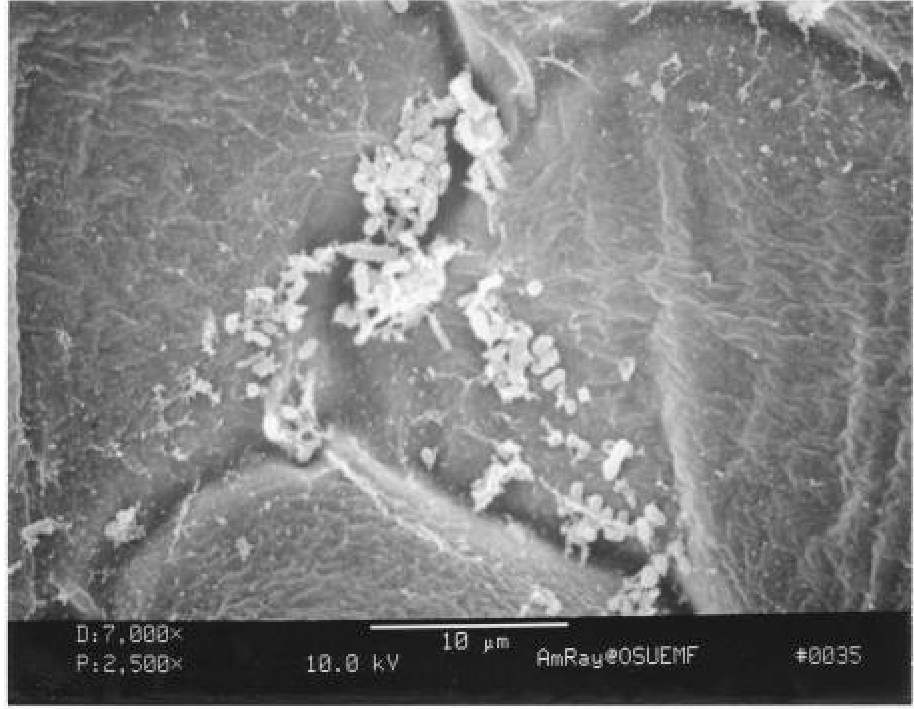
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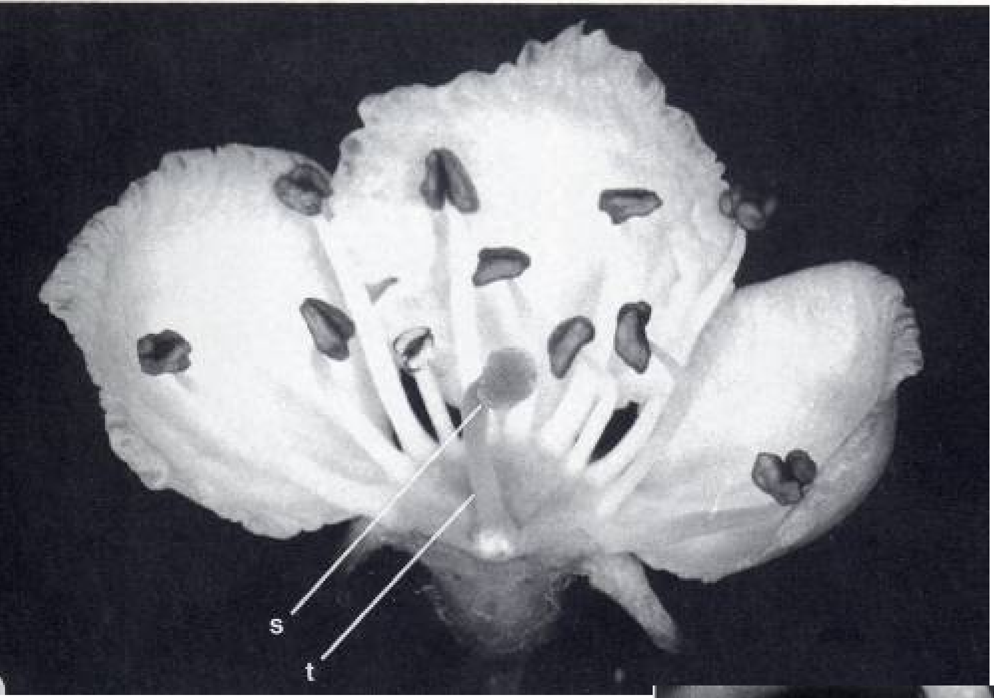
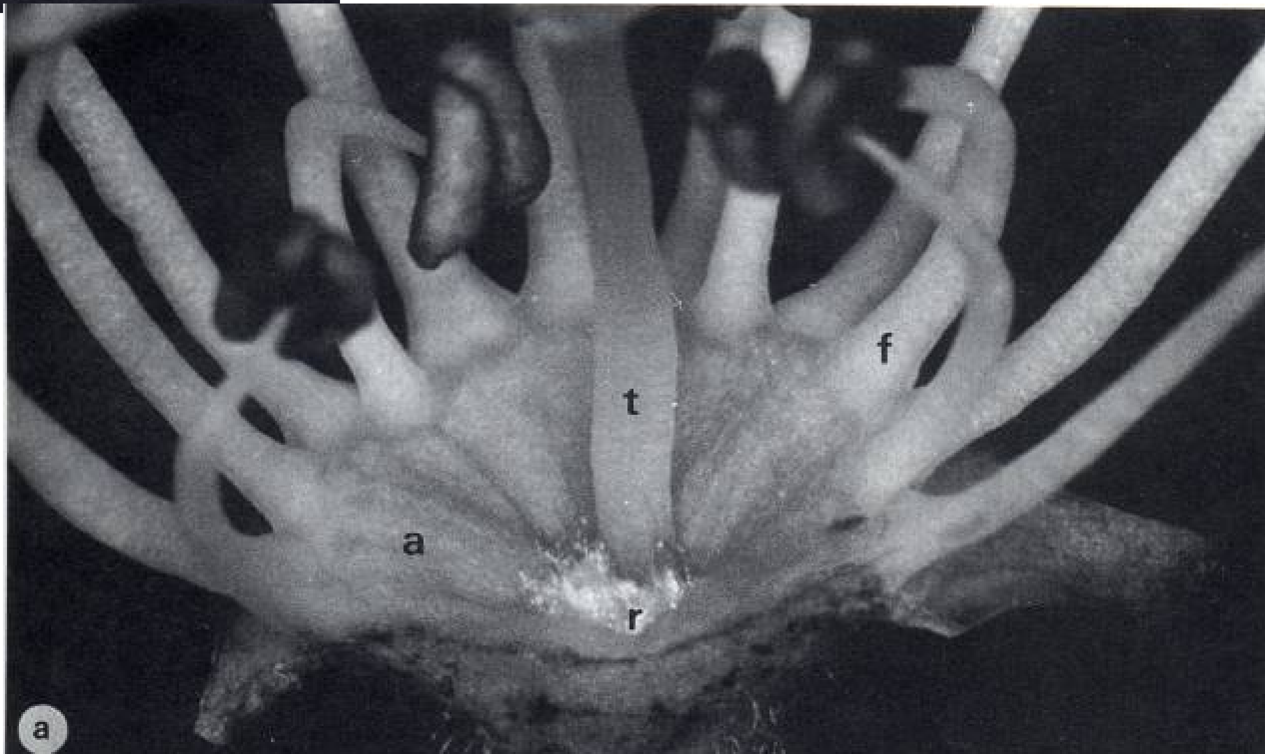


Plant associated microbes

Epiphytic growth on apple blossom by *Erwinia* bacteria
Fire Blight pathogen

Photos by Mark Wilson

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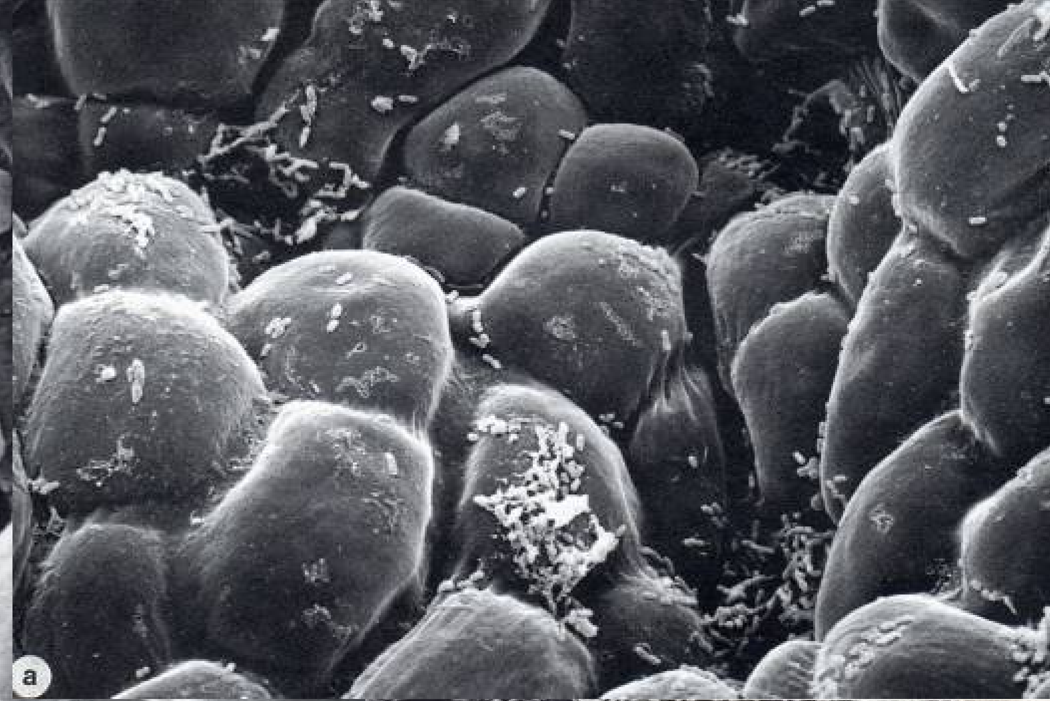
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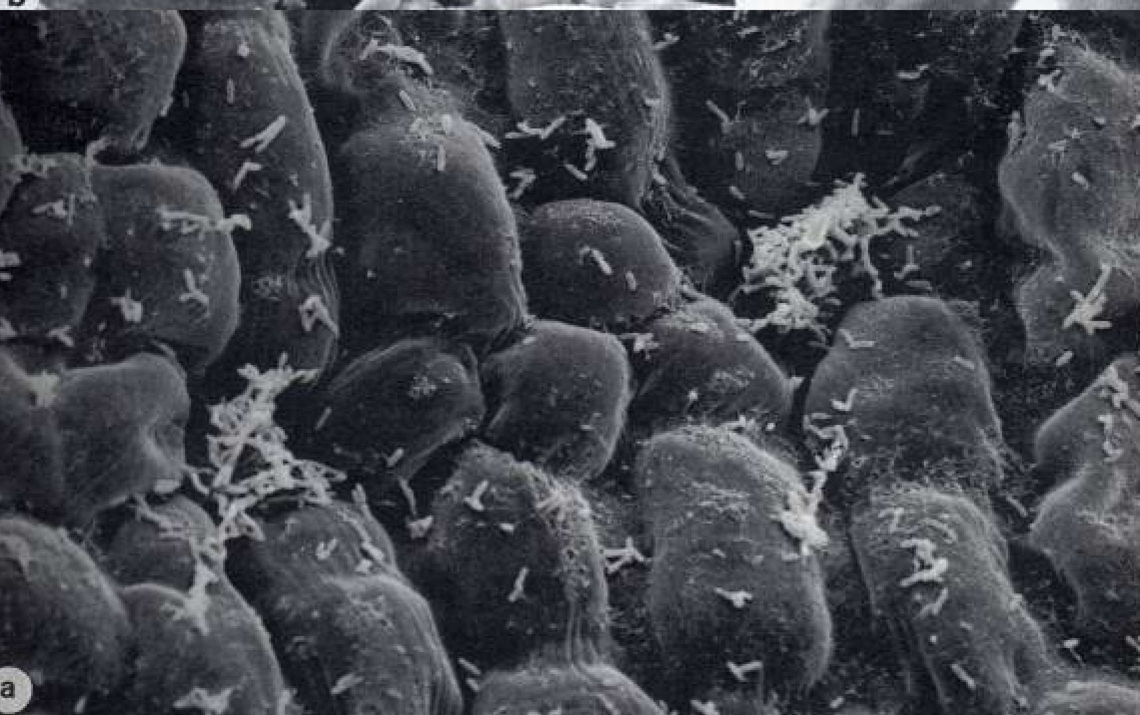
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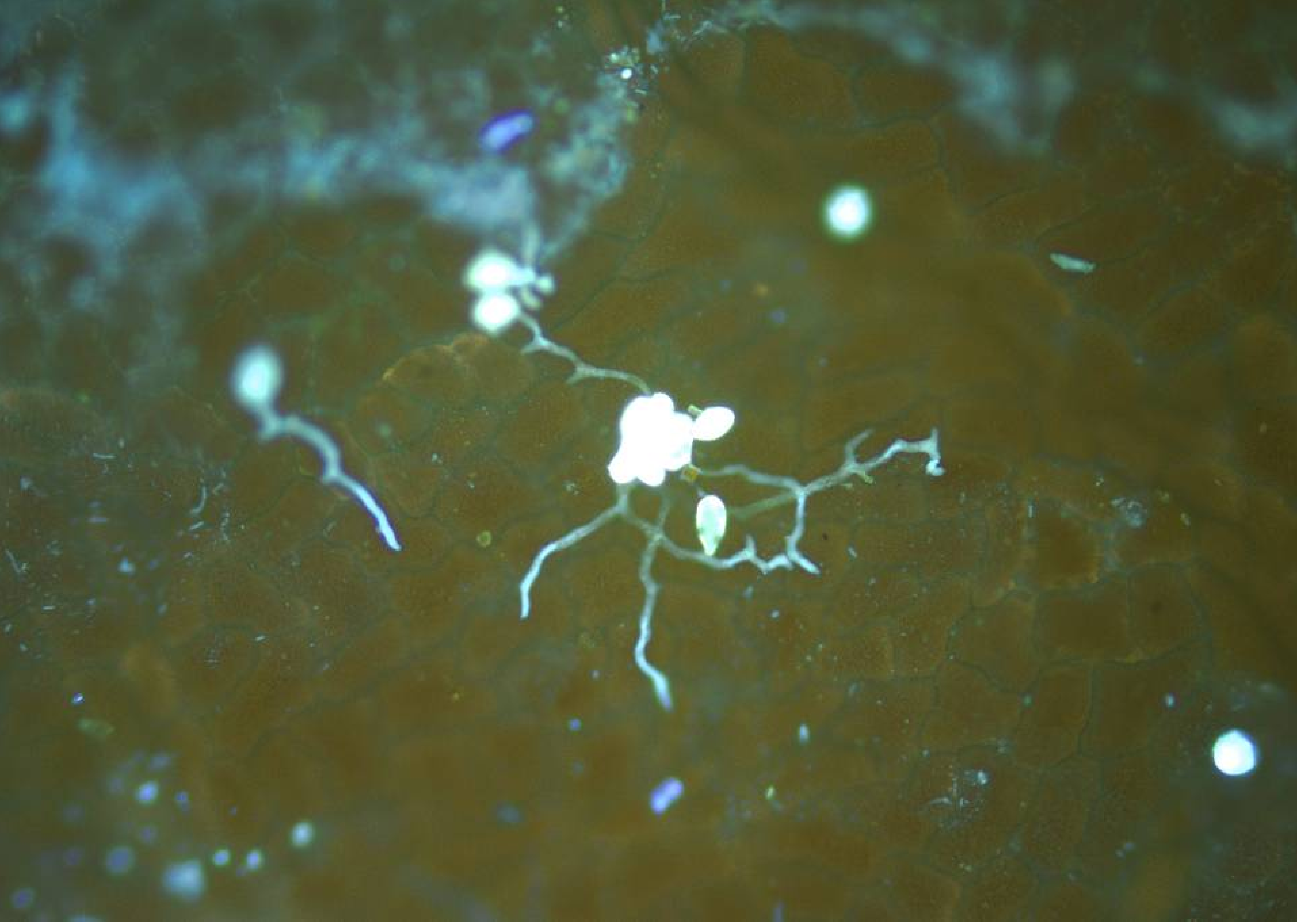
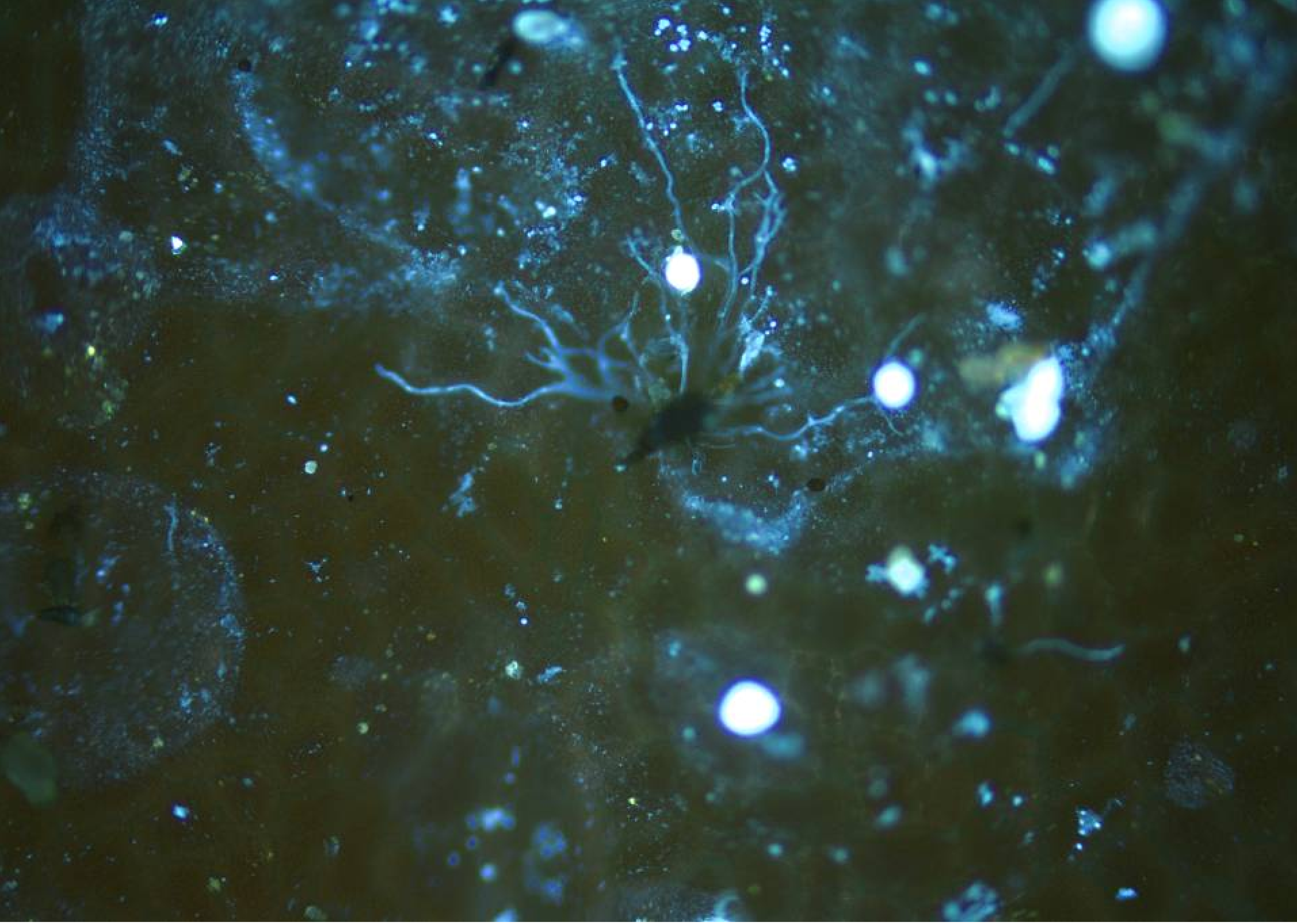
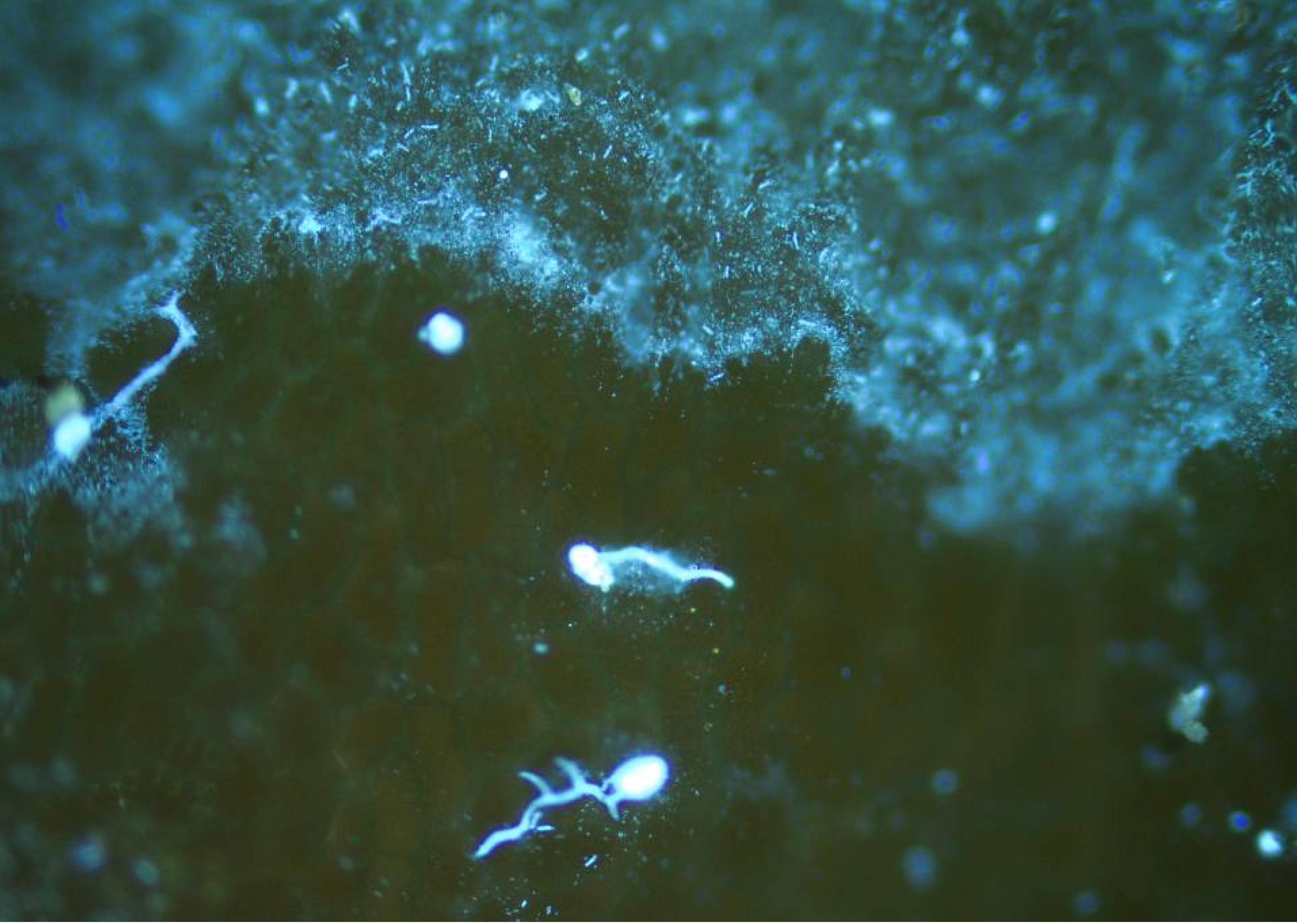
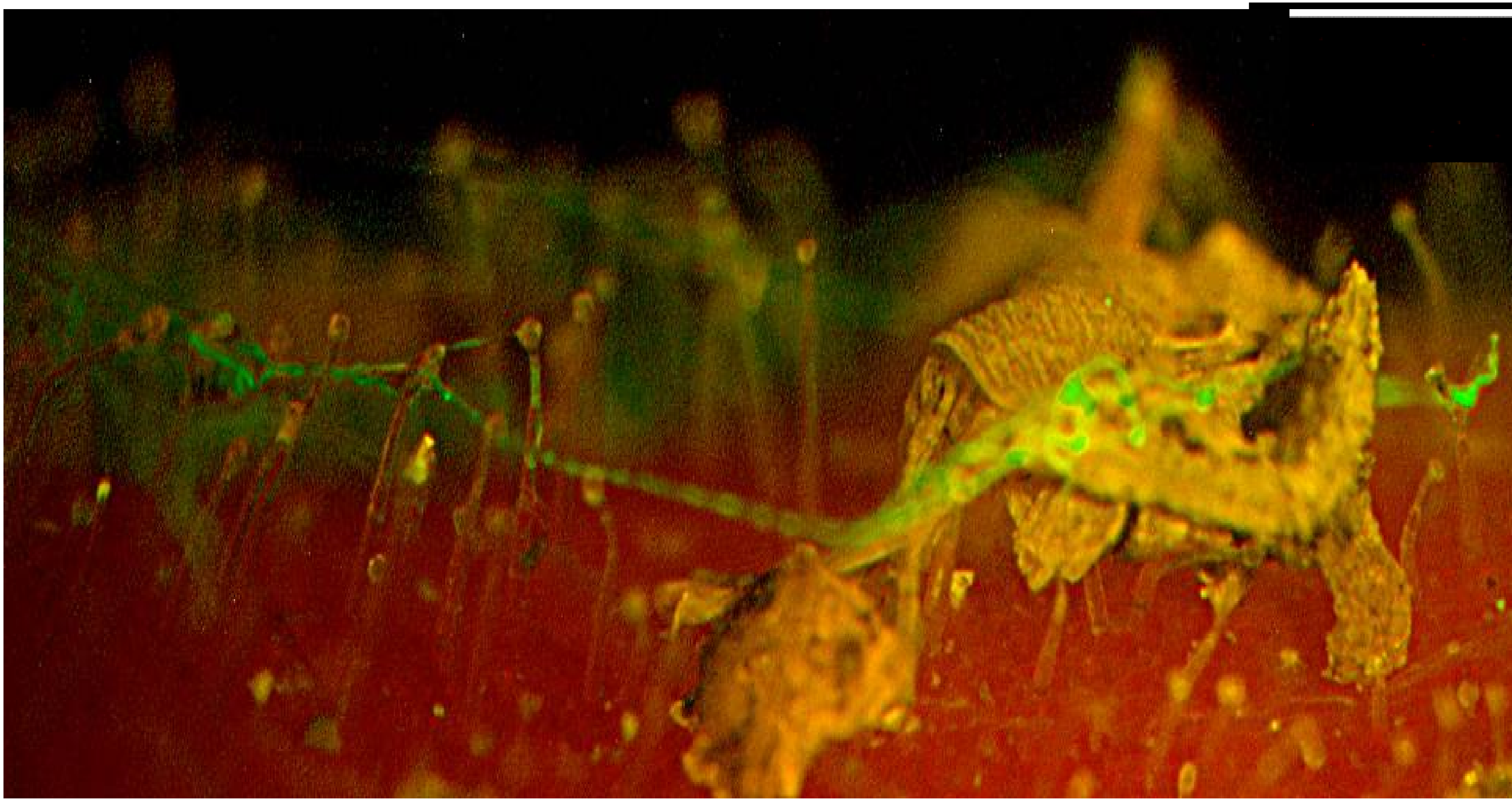




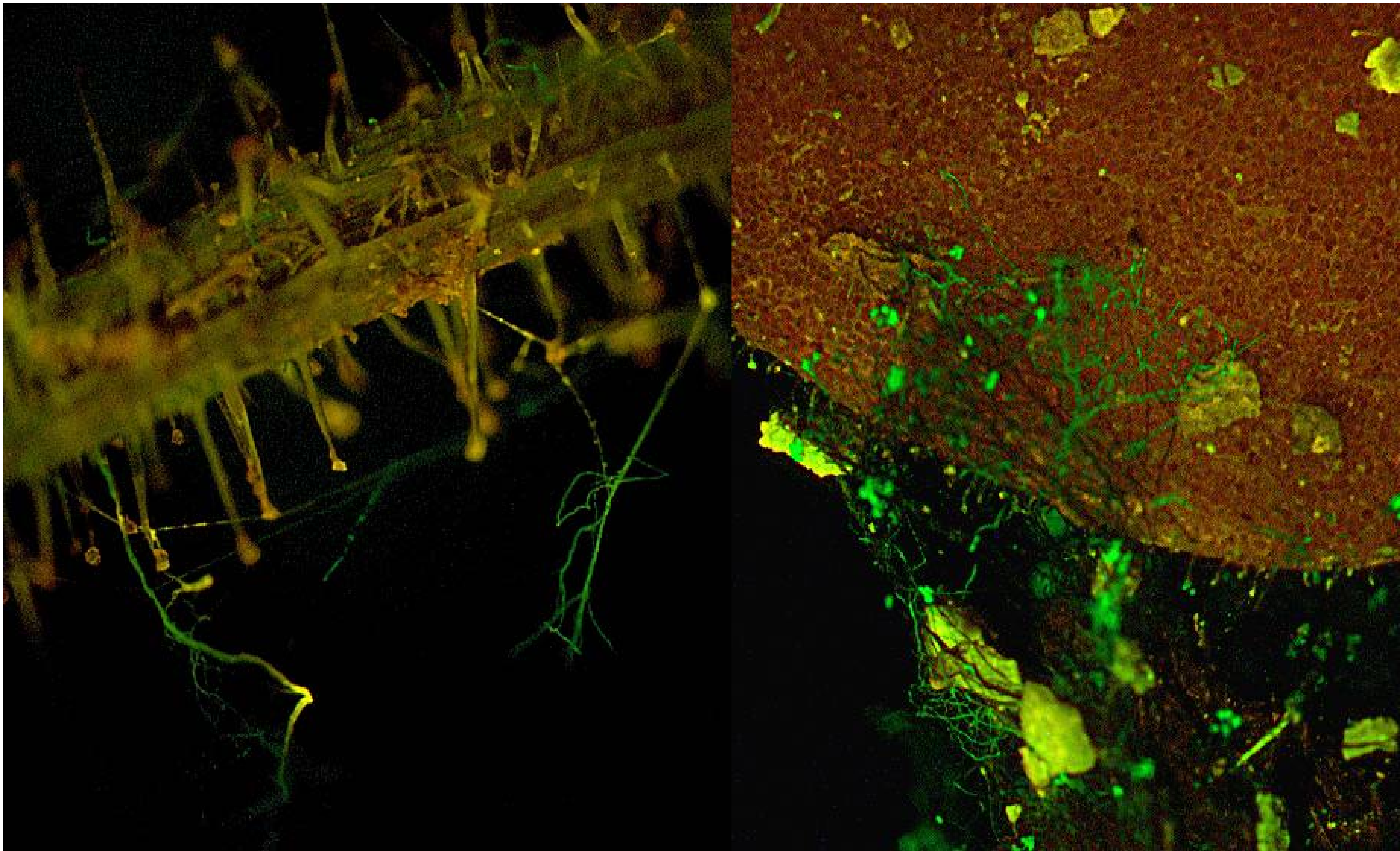


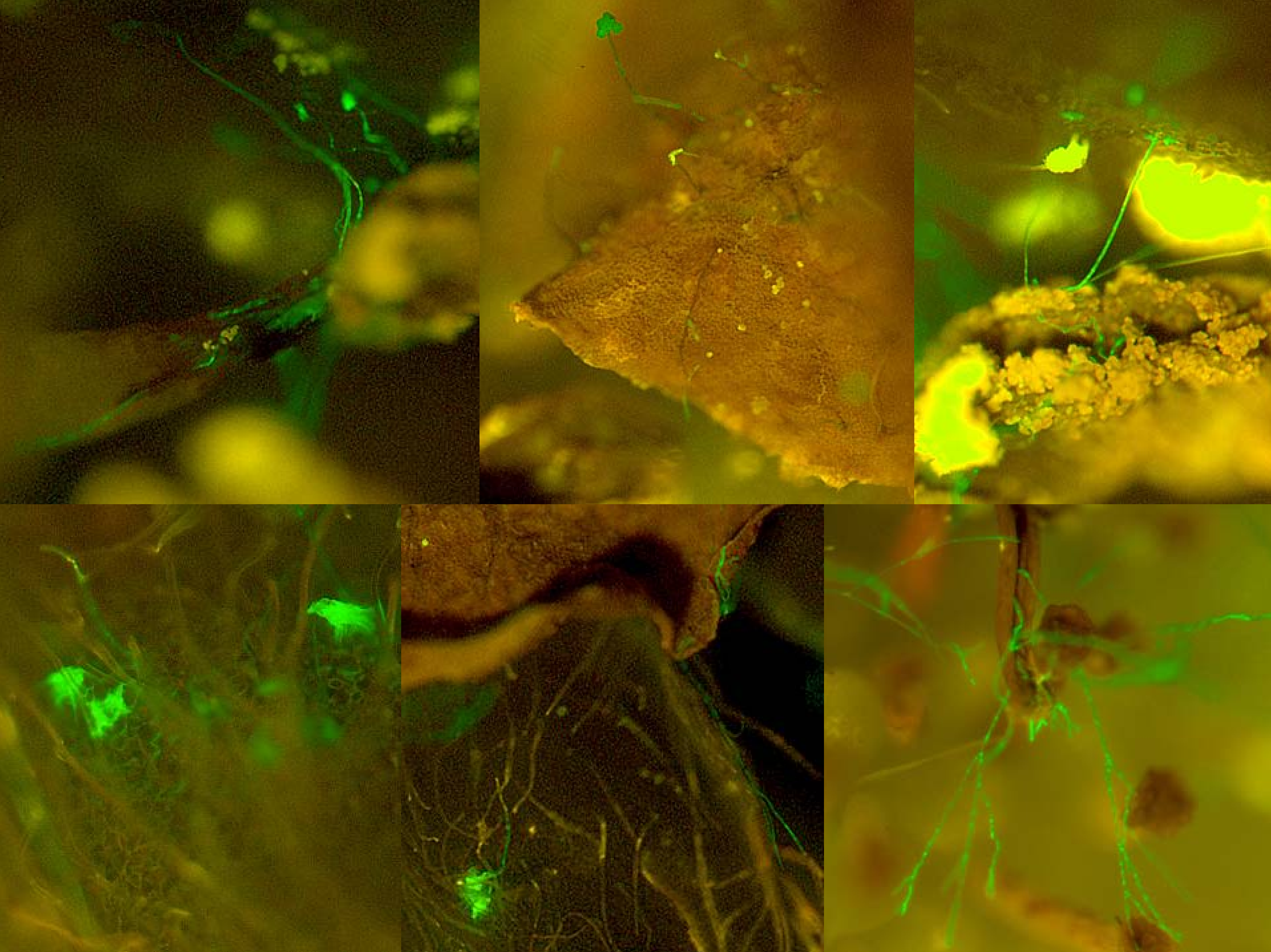
Fungal movement - Mycelia Bridging



Mycelia Bridging

Spread across touching leaves, across soil pore gaps





Root zone activity

The Rhizosphere

Rhizophere: zone of soil influenced significantly by the root, usually 2mm

In this photo, sand grains are bound to a root by hyphae from endophytes (fungi similar to mycorrhizae), and by polysaccharides secreted by the plant and the fungi, demonstrating the rhizosphere.

From: *Soil Biology Primer*Jerry Barrow, USDA-ARS Jornada Experimental Range, Las Cruces, NM.

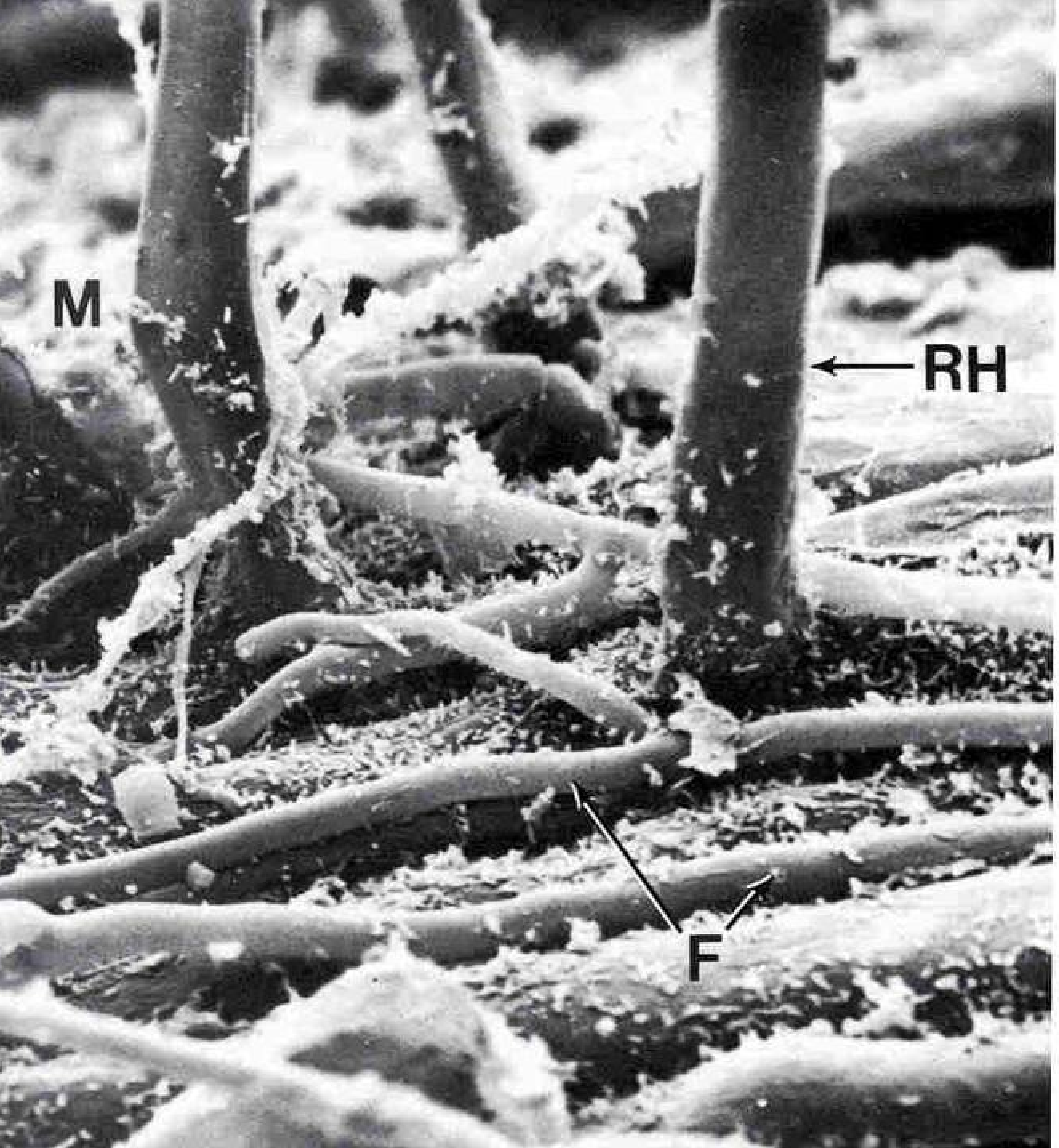

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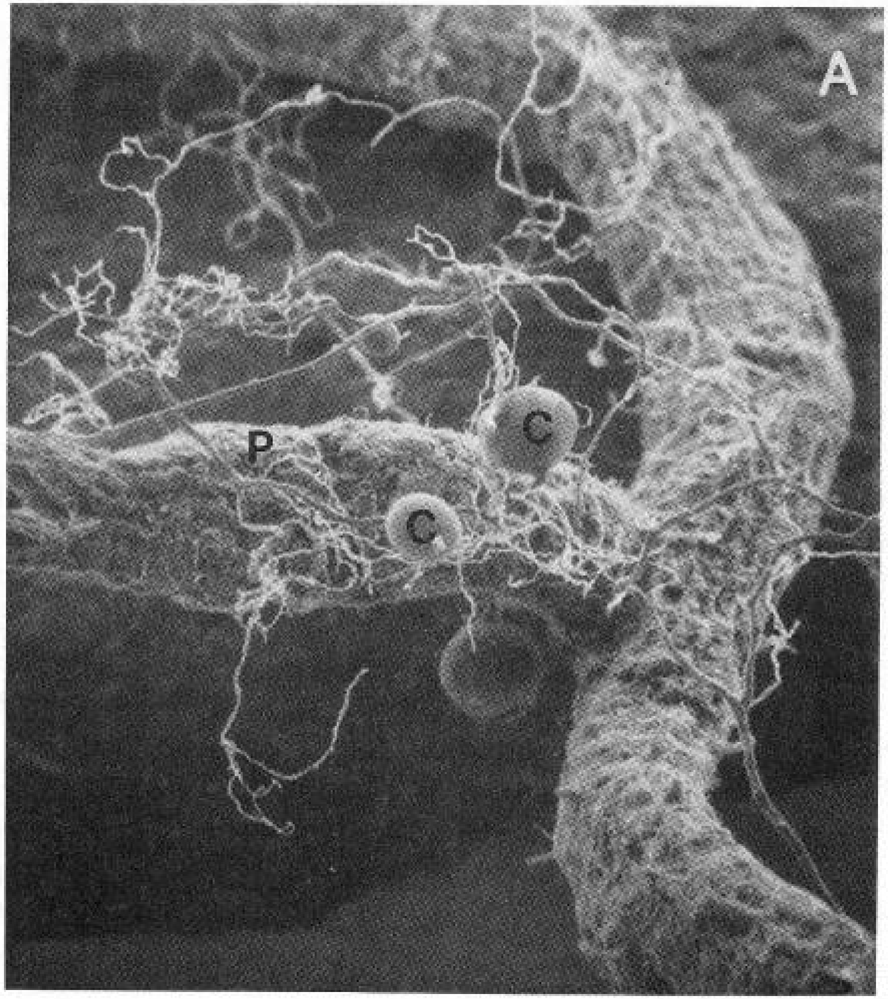
Figure 11.4. Scanning electron micrographs of *Glomus* spp. (*A*) Chlamydospores (C) and hyphae (P) of *G. fosciculatus* on a soybean root; (*B*) Sporocarp (S), probably containing a single spore and chlamydospore (C) of *G. mosseae;* (C) Chlamydospore of *G. mosseae*, showing the funnel-shaped subtending hypha (arrow). (From Brown and King, 1982.)



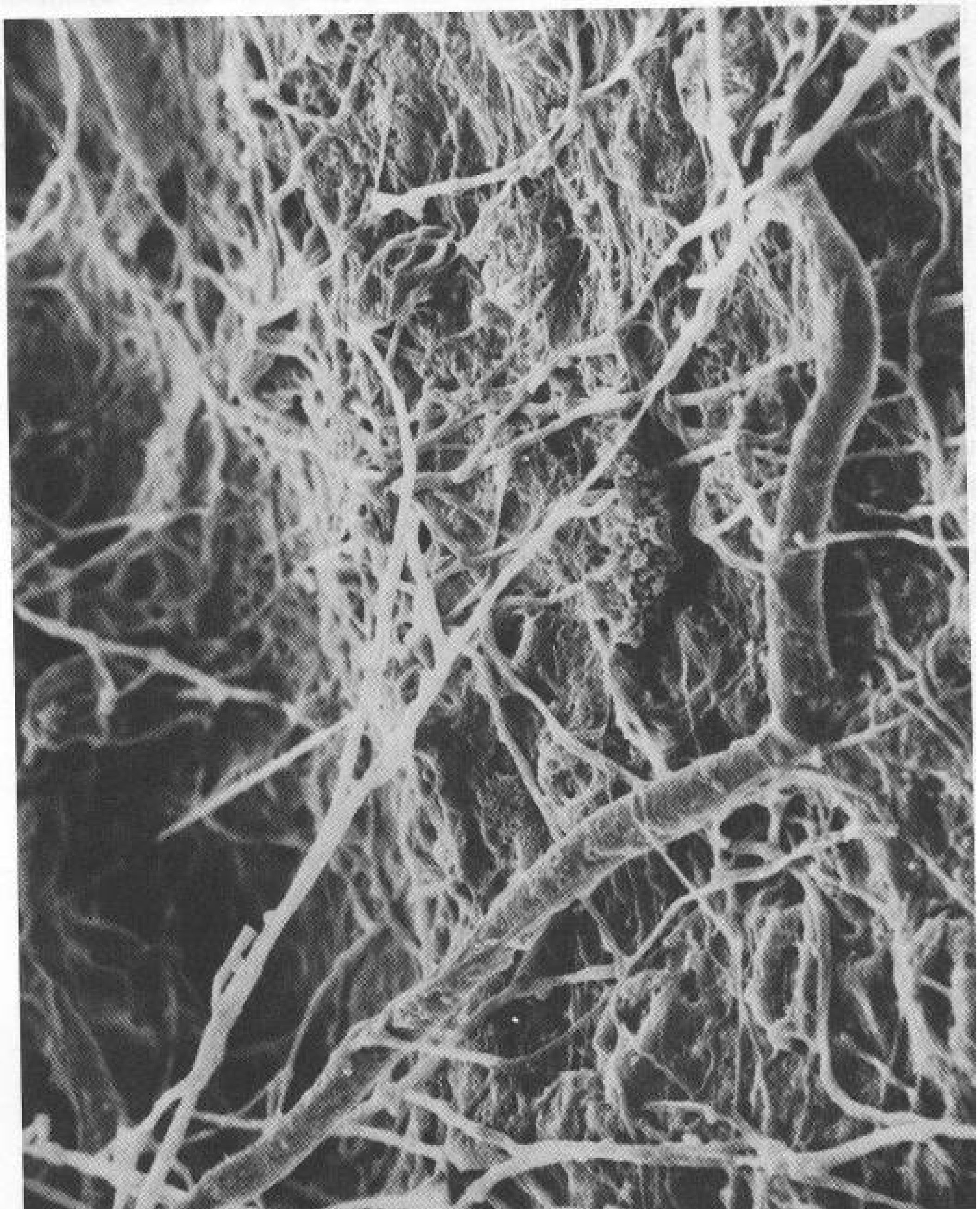
Mycorhizosphere

Extension of Rhizosphere concept

Exudates from hyphae of mycorrhizal fungi selectively increase some bacterial populations

Paul and Clark, 1989

Figure 3.2. Scanning electron micrograph of decomposing leaf litter. The bacteria tend to be hidden by slime but various sized filamentous organisms are readily apparent (photo courtesy of R. Todd.)



Decomposing organic matter

Bacteria and fungi are inside-out stomachs

Paul and Clark, 1989

Fungal dynamics of leaf decomposition

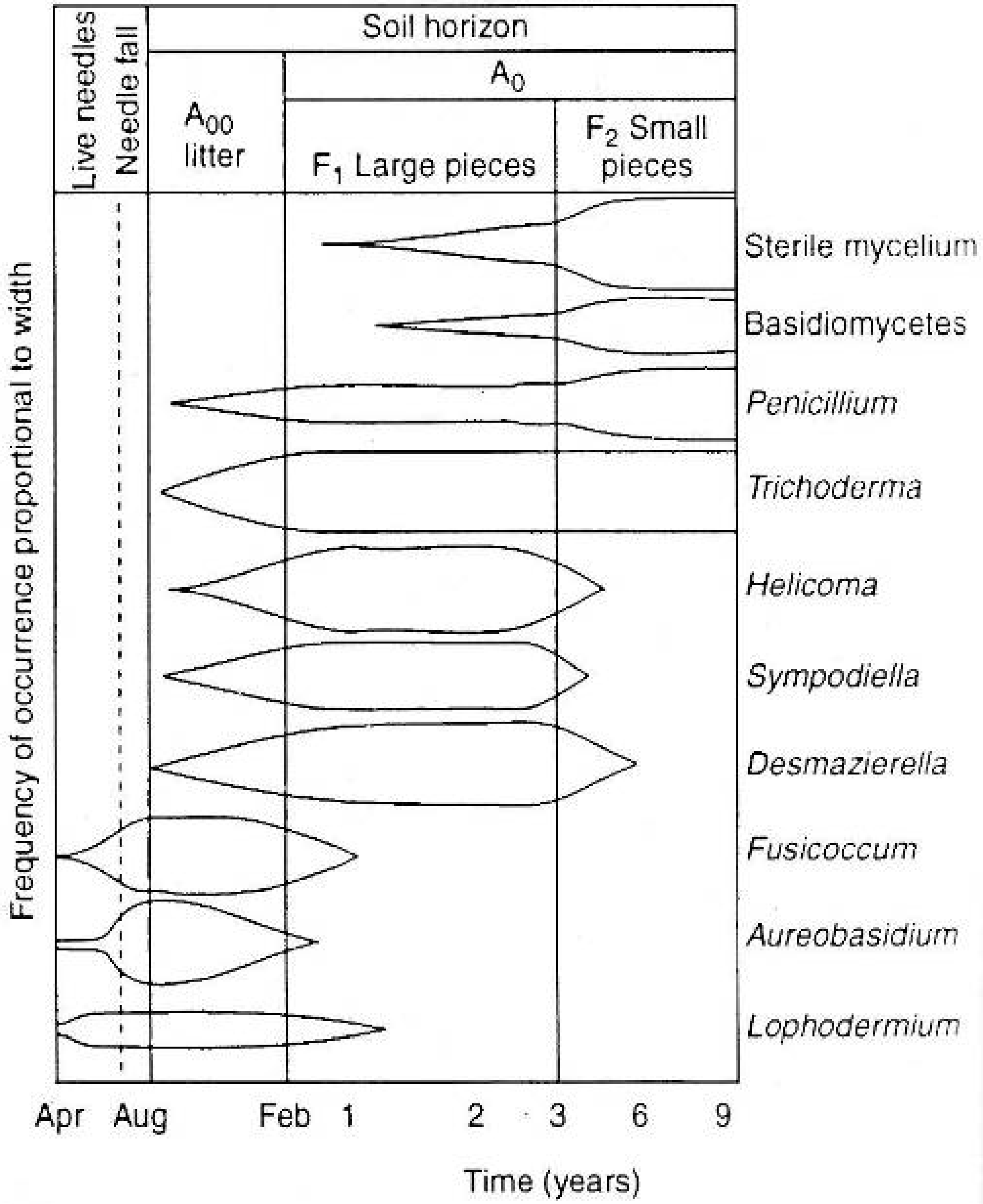
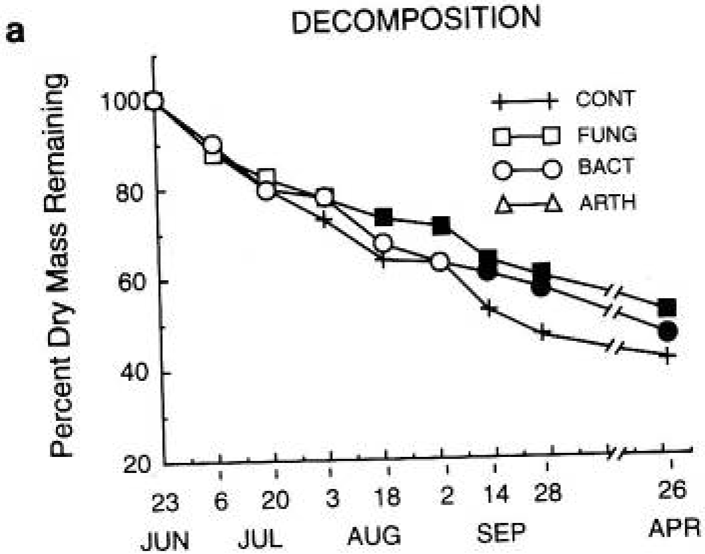


Figure 6.4

Succession of fungal populations on pine-needle litter from the initial populations on the live needles (lower left) to the

Atlas and Bartha, 1996

Decomposition of surface and buried leaf litter by fungi and bacteria



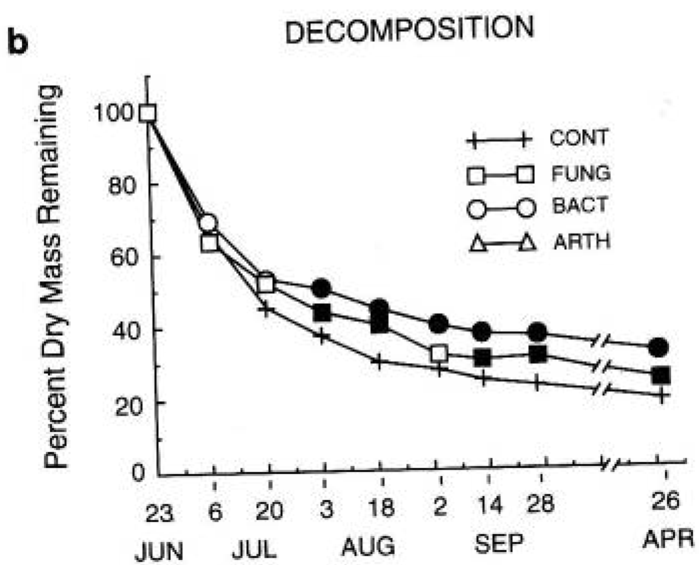
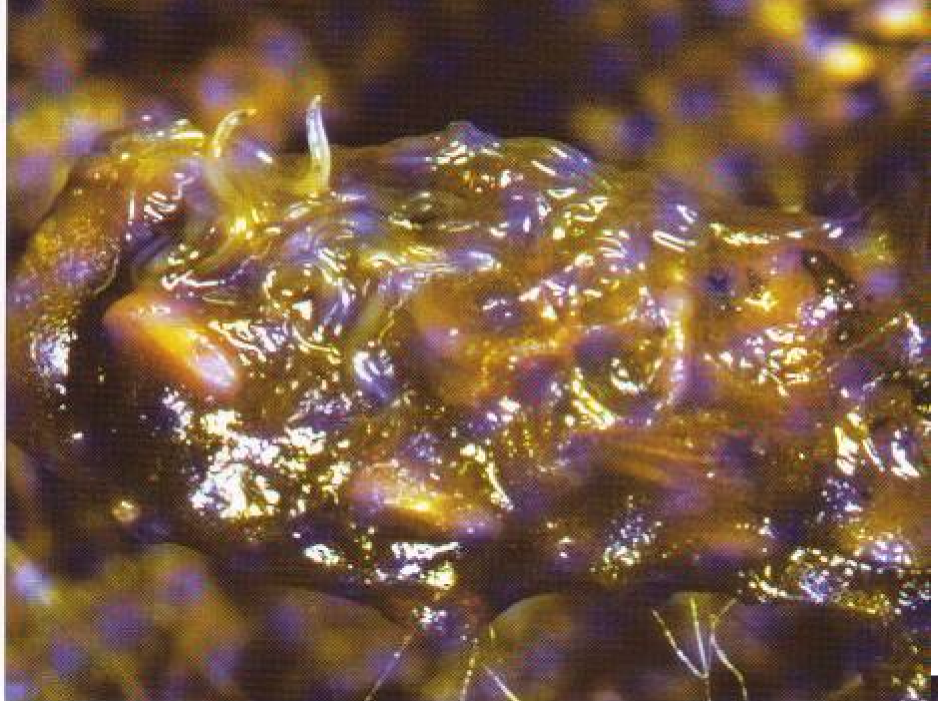


FIGURE 5.10 Mass loss rates for surface (a) and buried (b) rye litter over 320 days. CONT, Control situation; FUNG, fungicide, with ca. one half fungal population biomass; BACT, bactericide (oxycarbon); ARTH, arthropod repellant (naphthalene). (Modified from Beare *et al.*, 1992, with permission.)

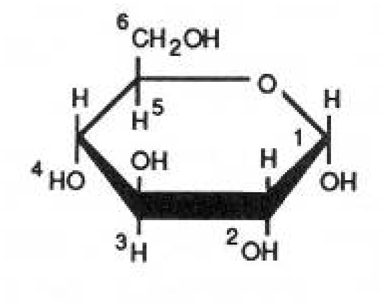
Coleman and Crossley, 1996



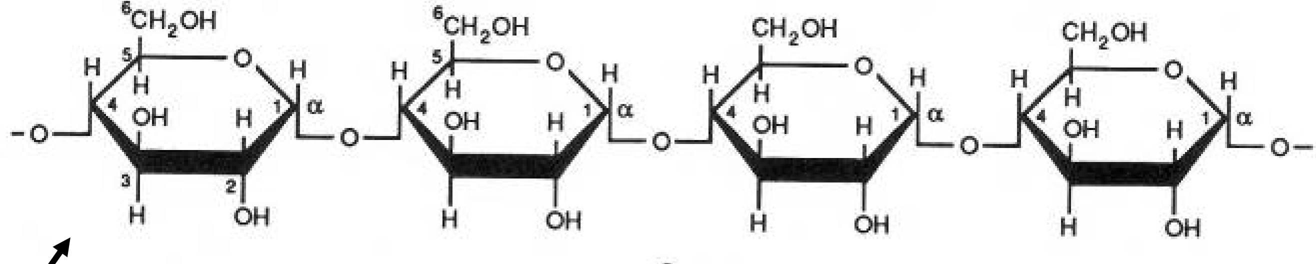
Decomposing millipede

Chitin exoskeleton
resists decomposition

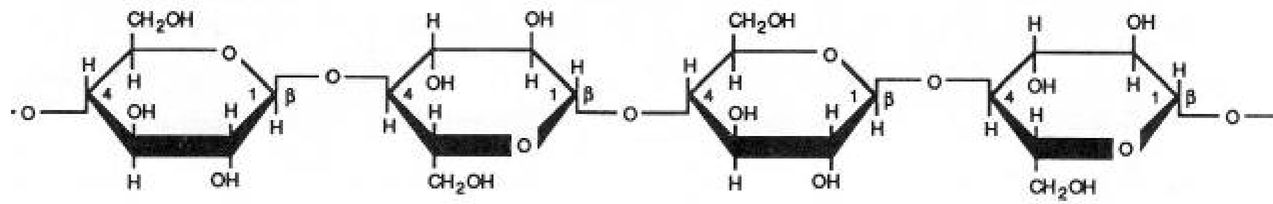
Lavies, 1993



Glucose

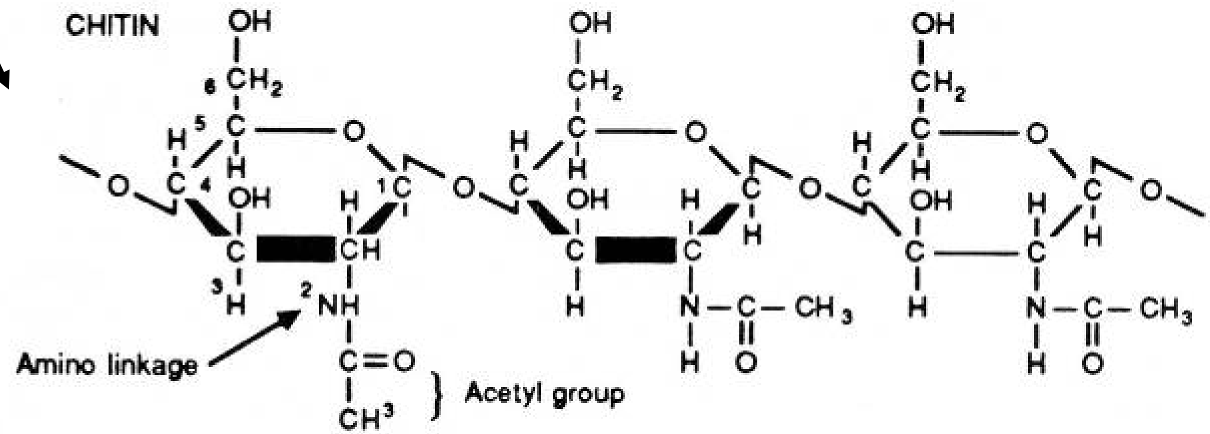


Starch



Cellulose

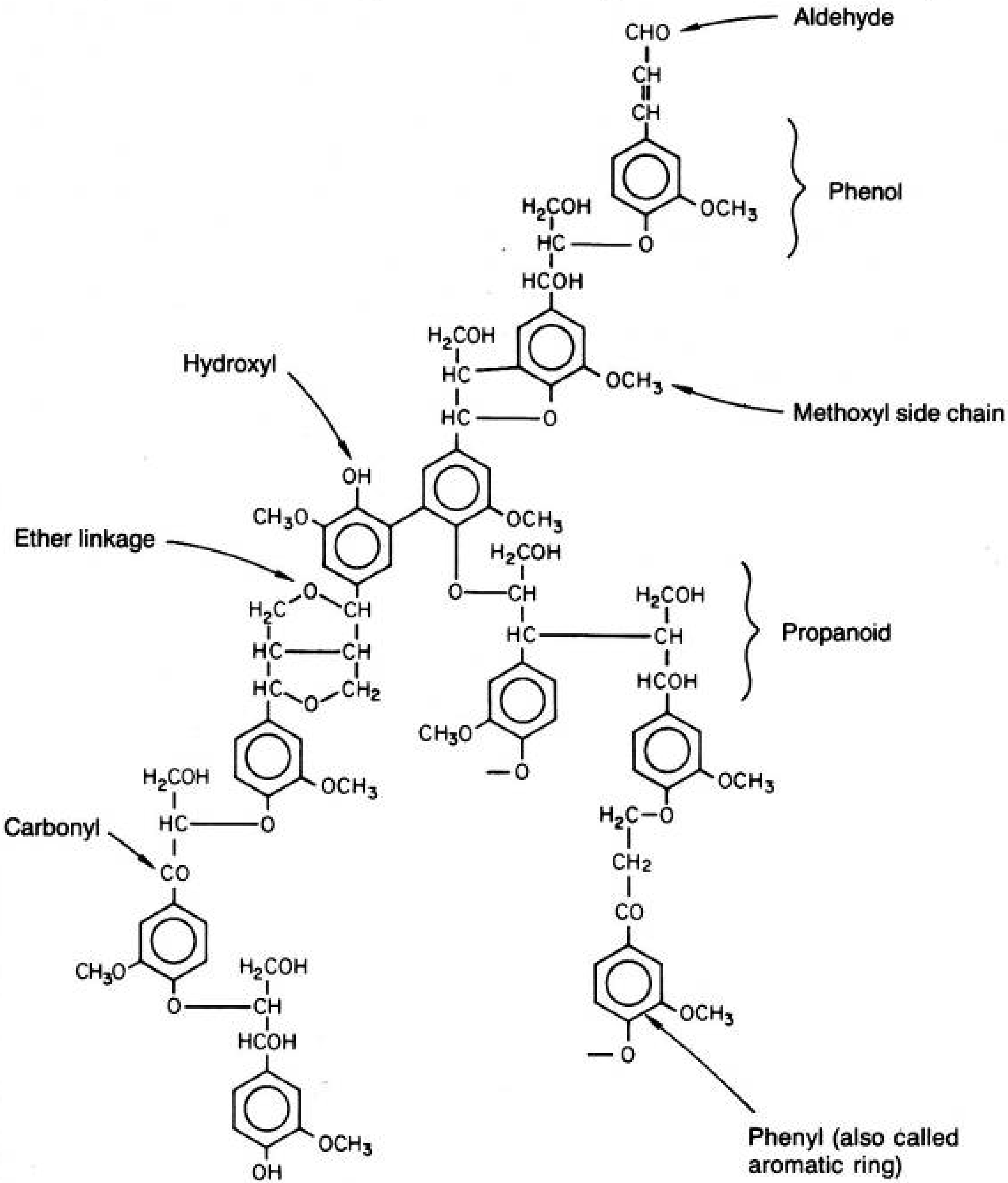
Figure 6.8. Structure of chitin, showing the *N*-acetylglucosamine group connected by β(1 → 4) linkages.



Chitin

Paul and Clark, 1989

Figure 6.4. Generalized lignin structure, showing the common functional group.



Lignin

Paul and Clark, 1989

Fungi - Decomposition of Organic Matter

Animal Manure

Wood

Humic Acid – Difficult to Decompose

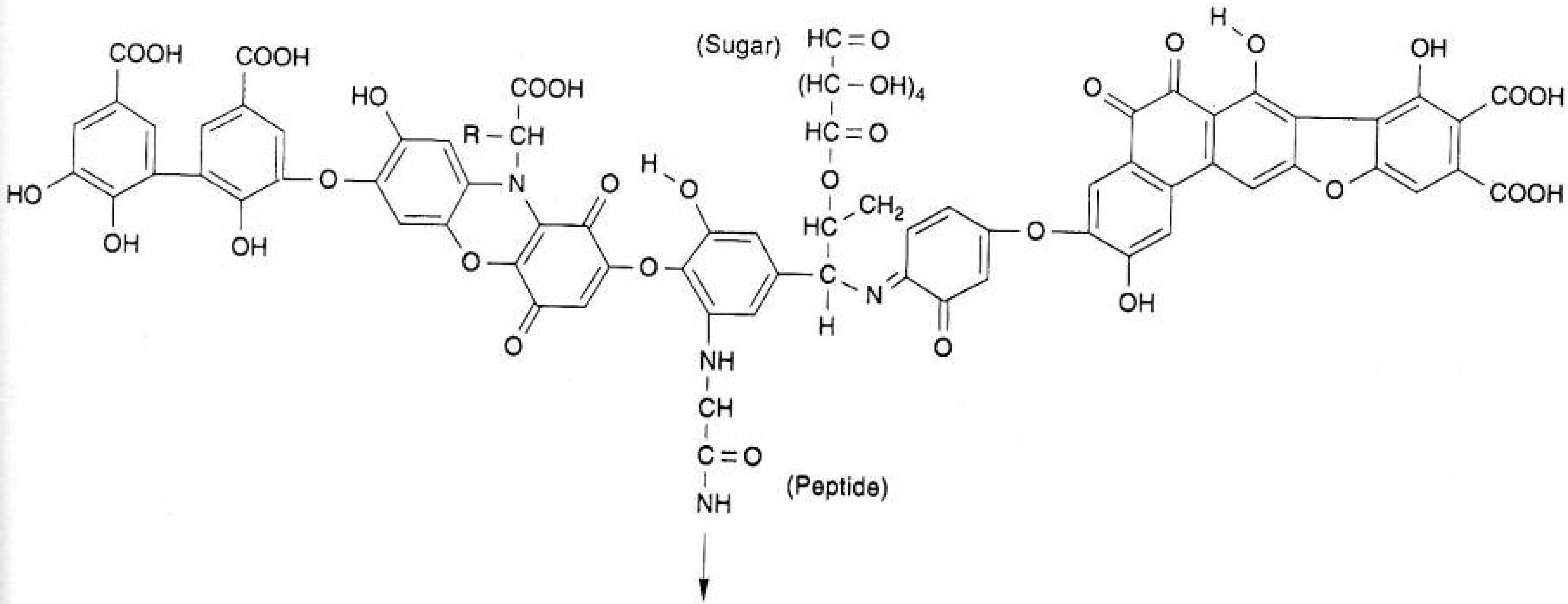
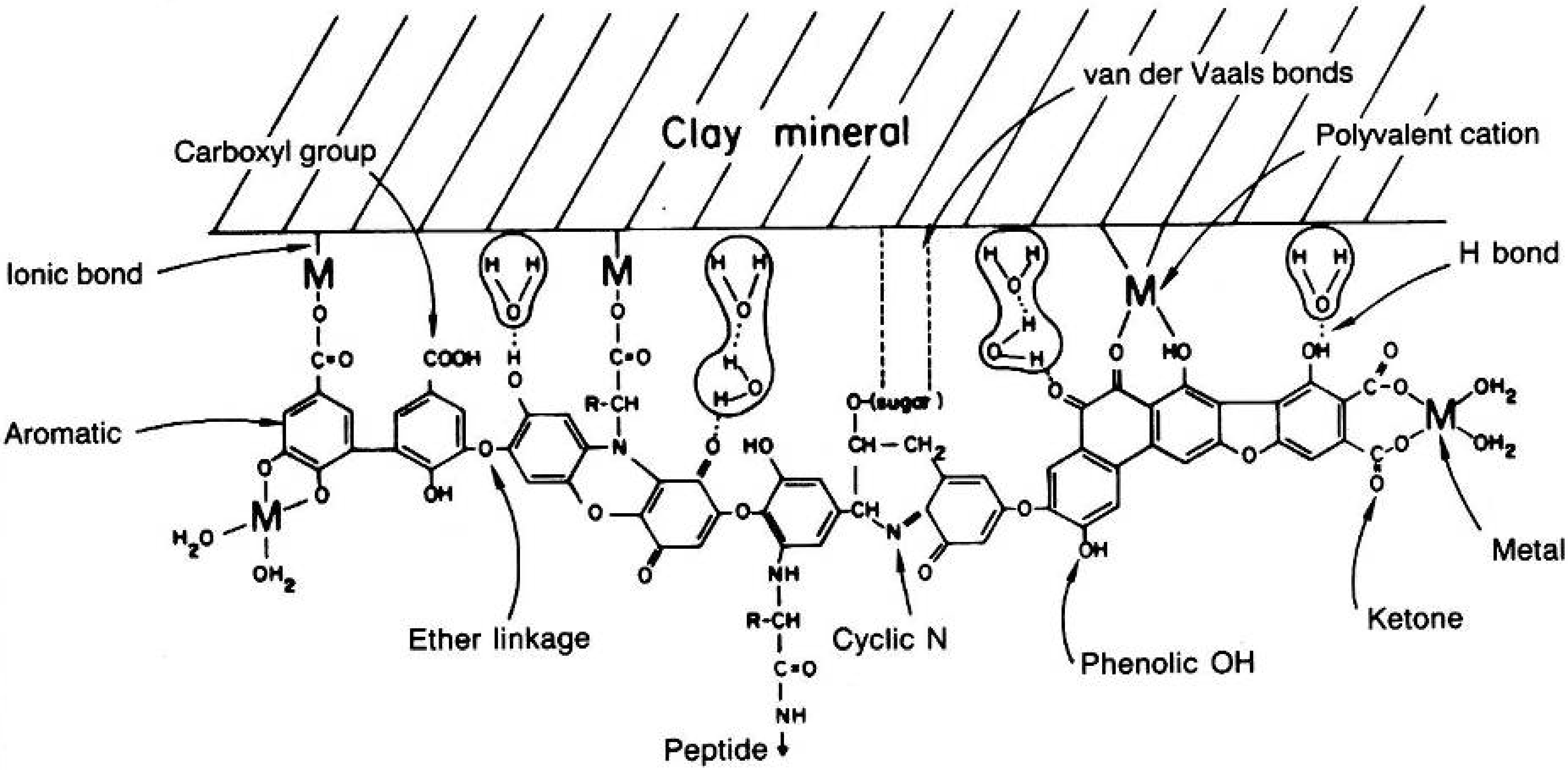


Figure 9.32
Proposed typical structure for humic acid. (Source: Stevenson 1976. *Bound and Conjugated Pesticide Residues*. Reprinted by permission, copyright American Chemical Society.)

Atlas and Bartha, 1998

Figure 6.14. Schematic diagram of a clay–humate complex in soil. (Adapted from Stevenson 1982a.)



Paul and Clark, 1989

Kennedy et al, 2004

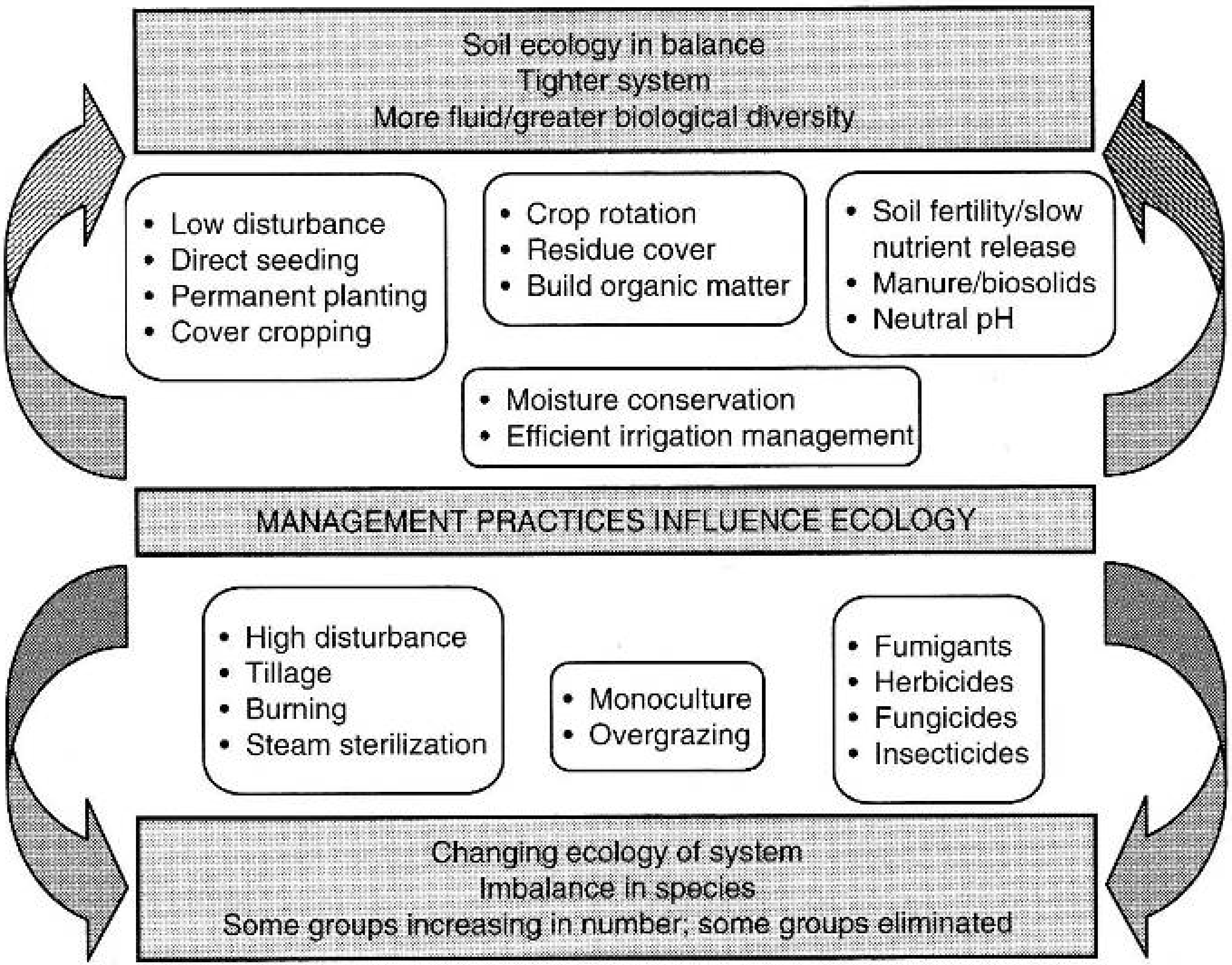


FIGURE 10.2 Management effects on soil biology. Practices that favor build-up of soil organic matter can lead to higher biological diversity, whereas practices that involve high disturbance and reliance on chemical additives can result in limited microbial diversity or elimination of some biological groups.

TABLE 10.1
Beneficial Functions of Soil Microorganisms in Agricultural Systems

- Release plant nutrients from insoluble inorganic forms
- Decompose organic residues and release nutrients
- Form beneficial soil humus by decomposing organic residues and through synthesis of new
- Produce plant growth-promoting compounds
- Improve plant nutrition through symbiotic relationships
- Transform atmospheric nitrogen into plant-available N
- Improve soil aggregation, aeration, and water infiltration
- Have antagonistic action against insects, plant pathogens, and weeds (biological control)
- Help in pesticide degradation

Kennedy et al, 2004

Oxidation – Reduction Reactions

$O_2 + 4\,H^+ + 4\,e^- \rightarrow 2\,H_2O$	reduction
$4\,Fe^{2+} \rightarrow 4\,Fe^{3+} + 4\,e^-$	oxidation
$O_2 + 4\,Fe^{2+} + 4\,H^+ \rightarrow 4\,Fe^{3+} + 2\,H_2O$	redox reaction