Department of soil science and agrochemistry

Lecture №4

Organic part of soil

Associate professor. Naushabayev Askhat

SOURCES OF ORGANIC SUBSTANCE OF SOILS AND ITS FRACTIONAL AND GROUP STRUCTURE

Primary sources of organic substances of the soil and biosphere are so-called primary producers, or autotrophs — the organisms capable to independent synthesis of organic substance from mineral compounds. In land ecosystems the overwhelming part of primary production is made by green plants.

To the soil come not only fossils of the died-off plants (primary organic substance), but also products of their microbiological transformation, and also the remains of animals (secondary organic substance).

Primary efficiency of various land ecosystems isn't identical and lies in limits:

- from 1-2 t/hectare in a year of dry organic substance (different types of the tundra)
- to 30 - 35 t/hectare a year (damp rainforests) (see tab. 3).

In agroecosystems to the soil comes the vegetable remains:

- from 2-3 t/hectare a year (tilled crops cultures)
- to 7-9 t/hectare a year (long-term herbs).

Receipt of secondary organic substances of a microbiological origin has to be several times below primary efficiency, but can reach units of tons on hectare a year. Receipt of organic substances with the dying-off soil fauna doesn't exceed in the majority of types of soils 100-200 kg/hectare a year. In soils of various type nature of distribution of the arriving organic residues on a soil profile isn't identical. In forest cenosis the main part of primary production arrives with a land waste, while in grassy substantially with the died-off roots. It plays an important role in the subsequent transformation vegetable the remains and soil formation. The chemical composition of the fossils coming to the soil in many respects depends on type of the died-off organisms (table).

Table . A chemical composition of the higher and lowest organisms, % to solid (A. E. Vozbutskaya)

Organisms	Ashes	Proteinaceous substances	Carbohydrates		Lignin	Lipids, tannins
			cellulose	Gemicellulose and other carbohydrates		
Bacteria	2—10	40—70	-	Есть	-	1—40
Seaweed	20—30	10—15	5—10	50—60	—	1—3
Lichens (bushy and lamellar)	2—6	3-5	5—10	60—80	8—10	1—3
Mosses	3—10	5—10	15-25	30—60	—	5—10
Filical	6-7	4-5	20—30	20—30	20-30	2—10
The coniferous: wood	0,1—1	0,5—1	45—50	15-25	25—30	2—12
Needles	2—5	3-8	15—20	15-20	20—30	15—20
The deciduous: wood	0,1—1	0,5—1	40—50	20—30	20—25	5—15
leaves	3-8	4—10	15-25	10—20	20—30	5—15
Long-term herbs: cereals	5—10	5—12	25—40	25—35	15—20	2—10
bean	5—10	10—20	25-30	15—25	15—20	2—10

In the majority of types of soils within a soil profile the main part of organic substance is presented by a "dead" reserve of organic compounds. The live biomass (эдафон) consisting of roots, microorganisms, representatives of soil fauna makes about 2-15% of the general content of organic substance in different soils.

Humus — the main part of organic substance of the soil which completely lost lines of an anatomic structure of organisms. Shares on 2 big groups of substances:

- nonspecific organic compounds which can be emitted from the soil, are identified and quantitatively defined (sugar, amino acid, a squirrel, the organic bases, tannins, organic acids, etc.). In the majority of mineral soils make units of percent of the general content of organic substance;

- specific humic compounds — the most characteristic specific part making about 80 — 90% of the general content of organic substance in the majority of mineral soils.

Humic substances on solubility and extractibility divide into big groups:

- fulvic acids (FC),
- humic acids (HA),
- humin;
- gimatomelan acids

The element structure of all preparations is various. At the same time all humic acids contain much more carbon less oxygen in comparison with fulvic acids. It testifies to a bigger enrichment of humic acids cyclic fragments while fulvic acids are more oxidized and rather enriched with aliphatic structures. Direct researches of products of destruction of humic acids confirm this situation. Judging by data of the element analysis, are most enriched with carbon, and consequently, and cyclic fragments humic acids of chernozems and sierozems while humic acids of soils of podsolic type according to the content of carbon and oxygen come nearer to fulvic acids a little.

The content of nitrogen in all groups of humic substances varies from 2.5 to 5.0%. On average humic substances are rather enriched with nitrogen in comparison with the initial vegetable remains.

It is connected with that in the course of a mineralization and humification of organic residues carbon is lost in the form of carbon dioxide in much bigger degree, than nitrogen.

Explain with existence of carboxyl groups the acid nature of humic substances. Most are enriched by them FA — about 700 - 900 m-eq. on 100g of air solid, to a lesser extent — group of companies HA— 300 - 400 m-eg. on 100g of substance.

Sorption of humic substances mineral compounds of a solid phase soils can proceed with participation of various mechanisms:

an ionic exchange,

a hemosorbtion,

complex formated sorption,

intermitsellyarny (more precisely, intermicelle) absorption of organic substances with not too high molecular weight clay minerals with the inflating crystal lattice. Basic possibility of formation of hydrogen communications and bridges through polyvalent cations at sorption interaction of clay minerals with humic substances is shown. The products of interaction which are formed thus are called sorption complexes, clay-humus complexes, mineral-organic compounds.

Complex and heteropolar salts can interact with soluble phosphates, many pesticides, changing their mobility, interphase distribution, receipt in plants. For example, for a number of herbicides change of herbicidal activity, and also ability to destruction at interaction with humic substances of soils is established.

As well as in case of formation of complex and heteropolar salts, carboxyl and fenolhydrooxide groups participate in interaction, however metal ions at such type of interaction easily dissociate and exchange with other cations of soil solution. The formed humat and fulvat of alkaline metals and ammonium well soluble input. In nature soluble humates and fulvata can be formed, apparently, only in the soda-saline soils. Humat and fulvat of Ca2+ and Mg2+ rather badly soluble in water also form humic accumulations in the soils sated with the bases.

Methods of extraction of a humus are based on transfer of insoluble compounds of humic acids to soluble humates of Na+, K+ or NH4+ by processing of the soil by solutions of alkalis of these cations or their salts.

ORGANIC SUBSTANCE IN VARIOUS TYPES OF SOILS

The organic substance is unequally distributed in profiles of various soils.

Over a wide range varies the maintenance of a humus in the top horizons of different soils — from 0.5 - 1 to 10 - 12% and more. Agricultural use in the conditions of the low standard of farming leads to decrease in level of a humidity.

Depending on a ratio of humic to fulvic acids (Sha: Sfa) distinguish the following types of a humus:

- humat (>1,5),
- fulvat-humat (1 - 1,5),
- humatno-fulvat (1 - 0,5)
- fulvat (<0,5).

In natural soil formation there is a regularity according to which under optimum conditions of a humus formation the humus which is rather enriched with humic acids (chernozems, humous soils) is formed. Development and an improvement of soils in some cases have usually ambiguous impact and on humus type, changing its qualitative structure.

Humus stocks in the separate horizons of soils or a soil profile in general are approximately proportional to the maintenance of a humus in the soil. It is used at comparative - balance estimates.

In all soils is held from 25 to 50% of the insoluble rest. This part of a humus is presented by compounds of two types: the semi-decayed vegetable remains of various extent of humification which don't manage to be selected before the analysis, and mineral-humus sorption complexes — the steadiest part of a humus.

The fossils coming to the soil are exposed to various biochemical and physical and chemical transformations as a result of which the most part of organic substance is oxidized to the final products, mainly of CO_2, H_2O and simple salts (mineralization), and smaller, having passed the difficult transformations called in total by hymification joins in structure of specific humic substances of the soil. In the most general view the concept of hymification can be defined as set of biochemical and physical and chemical processes which result is transformation of organic substances of the individual nature into the specific humic substances characterized by some general properties and lines of a structure. These general properties are listed above when determining the concept "humic substances".

At such definition of the concept "hymification" and “humus formation" make identical sense.

The most important quantitative characteristic of hymification - the coefficient of hymification of Ks representing a share (or percentage part) the carbon of fossils which joined in structure of humic substances at their full decomposition.

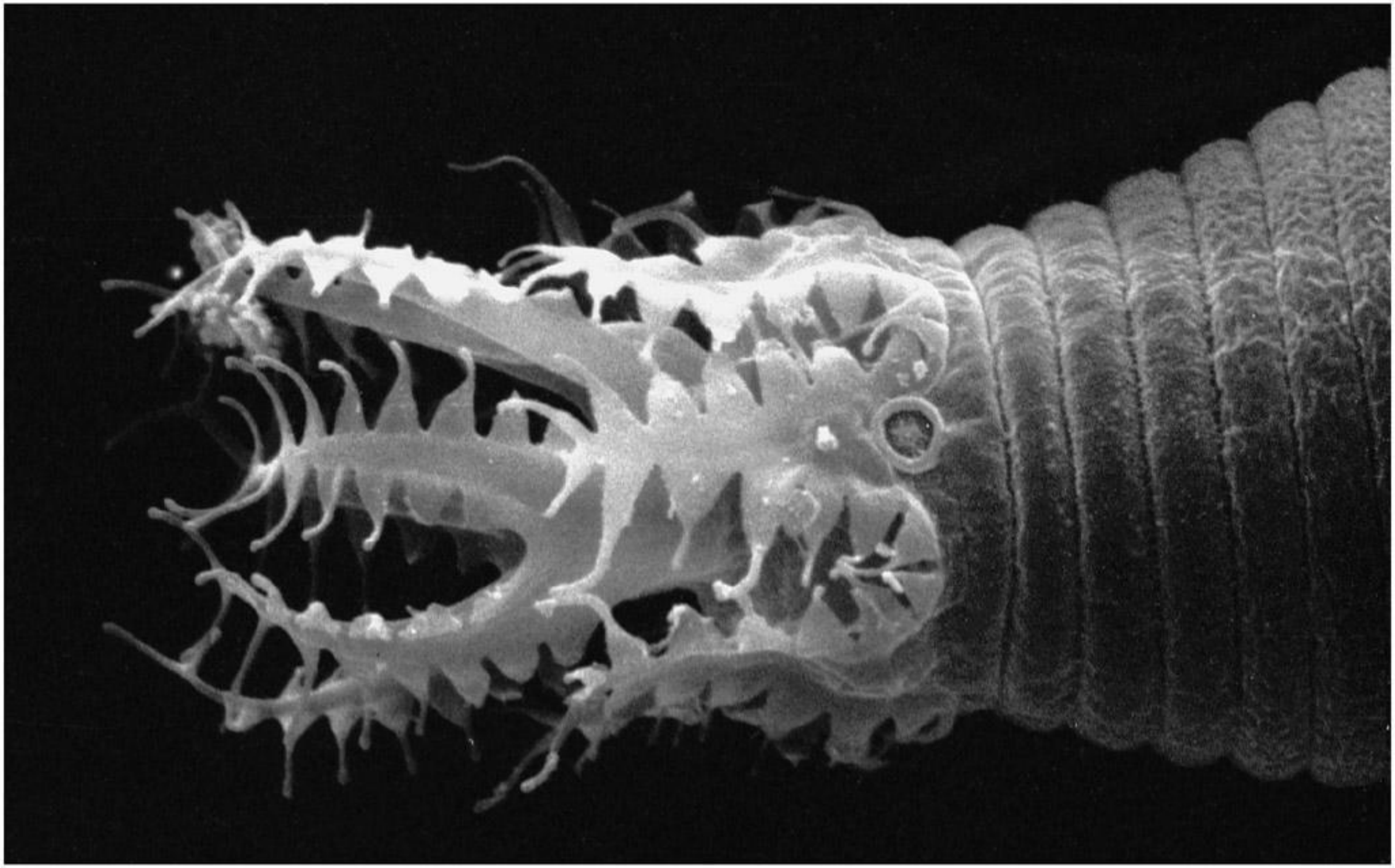
A. The functions connected with genesis of the soil, formation of its morphological features, material structure and properties.

- Formation specific organic profile.
- Aggregate formation with participation humic and the clay-humus of compounds. Interaction of a humus with minerals and formation microbiological and thermodynamic steady structures.
- Formation of addition and influence of humic substances on water physical properties of the soil.
- Formation labile migration ability of compounds and involvement of mineral components of the soil in biogeochemical circulation.
- Formation of sorption, acid and main and buffer properties of the soil.

B. The functions connected with direct participation of organic substances in food of plants.

- Source of elements of mineral food of the higher plants (N, P, K, Sa, microcells).
- A source of organic food for the heterotrophyc of organisms and influence on biological and biochemical activity of soils.
- CO2 source in a ground layer of air and influence on efficiency of photosynthesis.
- A source of biologically active agents in the soil having impact on growth and development of plants, mobilization of nutrients etc. (natural growth substances, enzymes, vitamins, etc.).
- Sanitary protection functions of organic substance.
- Acceleration of microbiological degradation of pesticides, catalytic influence on the speed of decomposition of pesticides.
- Fixing of the polluting substances in soils (sorption, a complex formation etc.), decrease in receipt of toxicant in a plant.
- Strengthening of migratory ability of toxicant.

Organisms and Ecology of the Soil



Head of a bacteria-feeding nermatode. (Sven Boström, Swedish Museum of Natural History)

Diversity of Soil Organisms

- Size of Organisms
  - Macrofauna – Moles, Prairie dogs, earthworms, millipeds
  - Mesofauna – Springtails and Mites
  - Microfauna – Nematodes and single-celled protozoans
  - Flora – Plants Roots
  - Microorganisms – Fungi, Bacteria, and Actinomycetes

Diversity of Soil Organisms

- Types of Diversity
  - Species Diversity – The mix of species present
  - Functional Diversity –

Diversity of Soil Organisms

- Ecosystem Dynamics
  - Functional Redundancy – Several organisms can carry out each ecosystem service.
    - This redundancy leads to ecosystem stability and resilience
  - Keystone Species – A species that is unique in filling an ecological niche and is therefore integral to the functioning of that system.
- Global Biodiversity – Great genetic resource of soil organisms.

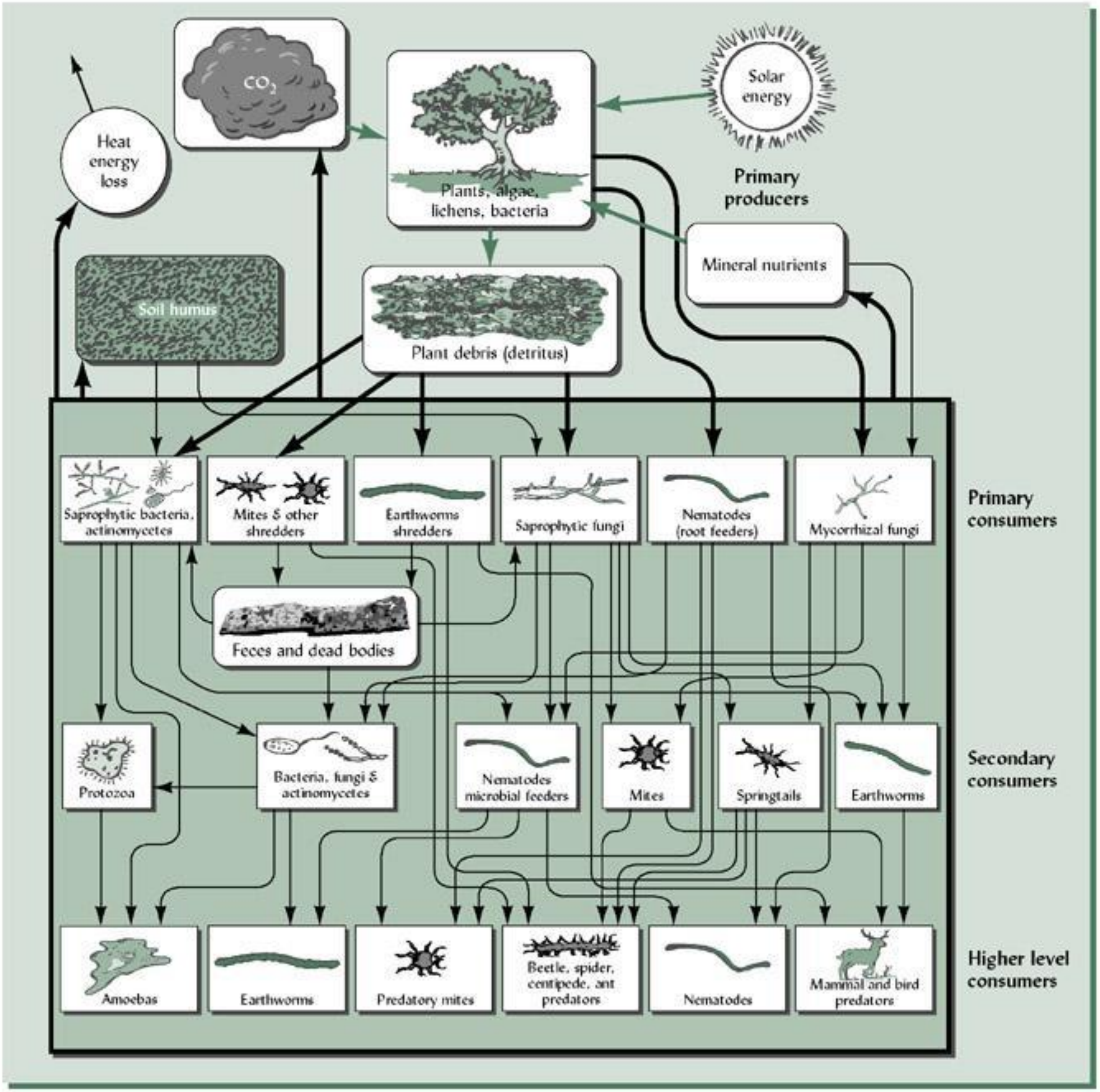
TABLE 11.1 General Classification of Some Important Groups of Soil Organisms

Some organisms subsist on living plants (herbivores), others on dead plant debris (detritivores). Some consume animals (predators), some devour fungi (fungivore) or bacteria (bacterivores), and some live off of, but do not consume, other organisms (parasites). Heterotrophs rely on organic compounds for their carbon and energy needs while autotrophs obtain their carbon mainly from carbon dioxide and their energy from photosynthesis or oxidation of various elements.

Generalized grouping (width in mm)	*Major specific groups*	*Examples*
Macrofauna (>2mm)		
All heterotrophs,	Vertebrates	Gophers, mice, moles
largely herbivores and detritivores	Arthropods	Ants, beetles and their larvae, centipedes, grubs, maggots, millipedes, spiders, termites, woodlice
	Annelids	Earthworms
	Mollusks	Snails, slugs
Macroflora		
Largely autotrophs	Vascular plants	Feeder roots
	Bryophytes	Mosses
Mesofauna (0.1–2 mm)		
All heterotrophs,	Arthropods	Mites, collembola (springtails)
largely detritivores	Annelids	Enchytraeid (pot) worms
All heterotrophs, largely predators	Arthropods	Mites, protura
Microfauna (<0.1 mm)		
Detritivores,	Nematodes	Nematodes
predators, fungivores,	Rotifera[a]	Rotifers
bacterivores	Protozoa[a]	Amoebae, ciliates, flagellates
Microflora (<0.1 mm)		
Largely autotrophs	Vascular plants	Root hairs
	Algae	Greens, yellow-greens, diatoms
Largely heterotrophs	Fungi	Yeasts, mildews, molds, rusts, mushrooms
	Actinomycetes	Many kinds of actinomycetes
Heterotrophs and autotrophs	Bacteria[b] (and Archaea[b])	Aerobes, anaerobes
	Cyanobacteria	Blue-green algae

[a] Generally classified in the kingdom *Protista*.
[b] Traditionally classified together in the kingdom *Monera*, these organisms have prokaryotic cells but are classed in the domains Bacteria or Archaea based on differences in RNA.

Figure 11.1



Heat energy loss
CO_2
Plants, algae, lichens, bacteria
Solar energy
Primary producers
Mineral nutrients
Soil humus
Plant debris (detritus)
Saprophytic bacteria, actinomycetes
Mites & other shredders
Earthworms shredders
Saprophytic fungi
Nematodes (root feeders)
Mycorrhizal fungi
Primary consumers
Feces and dead bodies
Protozoa
Bacteria, fungi & actinomycetes
Nematodes microbial feeders
Mites
Springtails
Earthworms
Secondary consumers
Amoebas
Earthworms
Predatory mites
Beetle, spider, centipede, ant predators
Nematodes
Mammal and bird predators
Higher level consumers

Figure 11.2

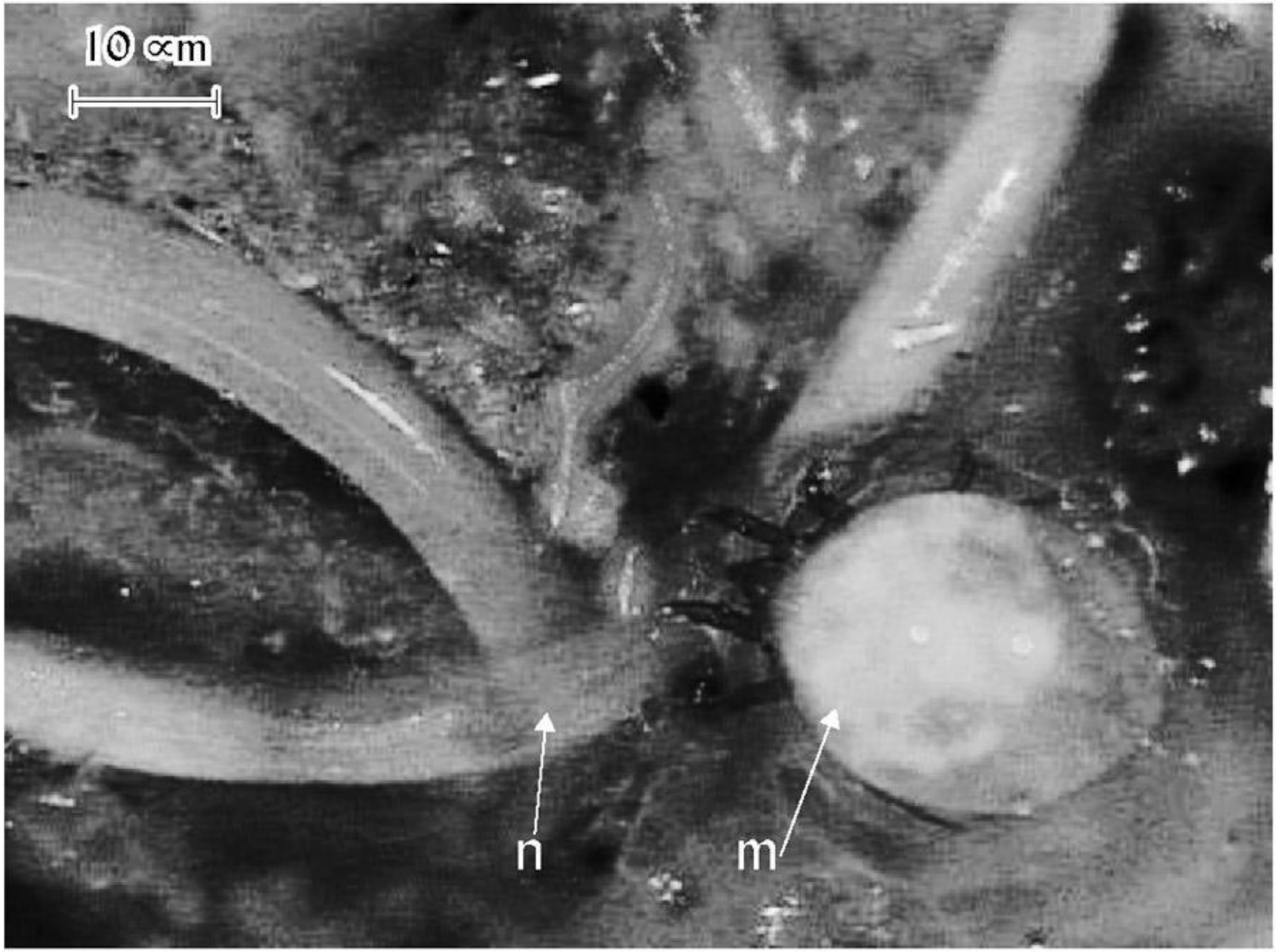


Figure 11.3

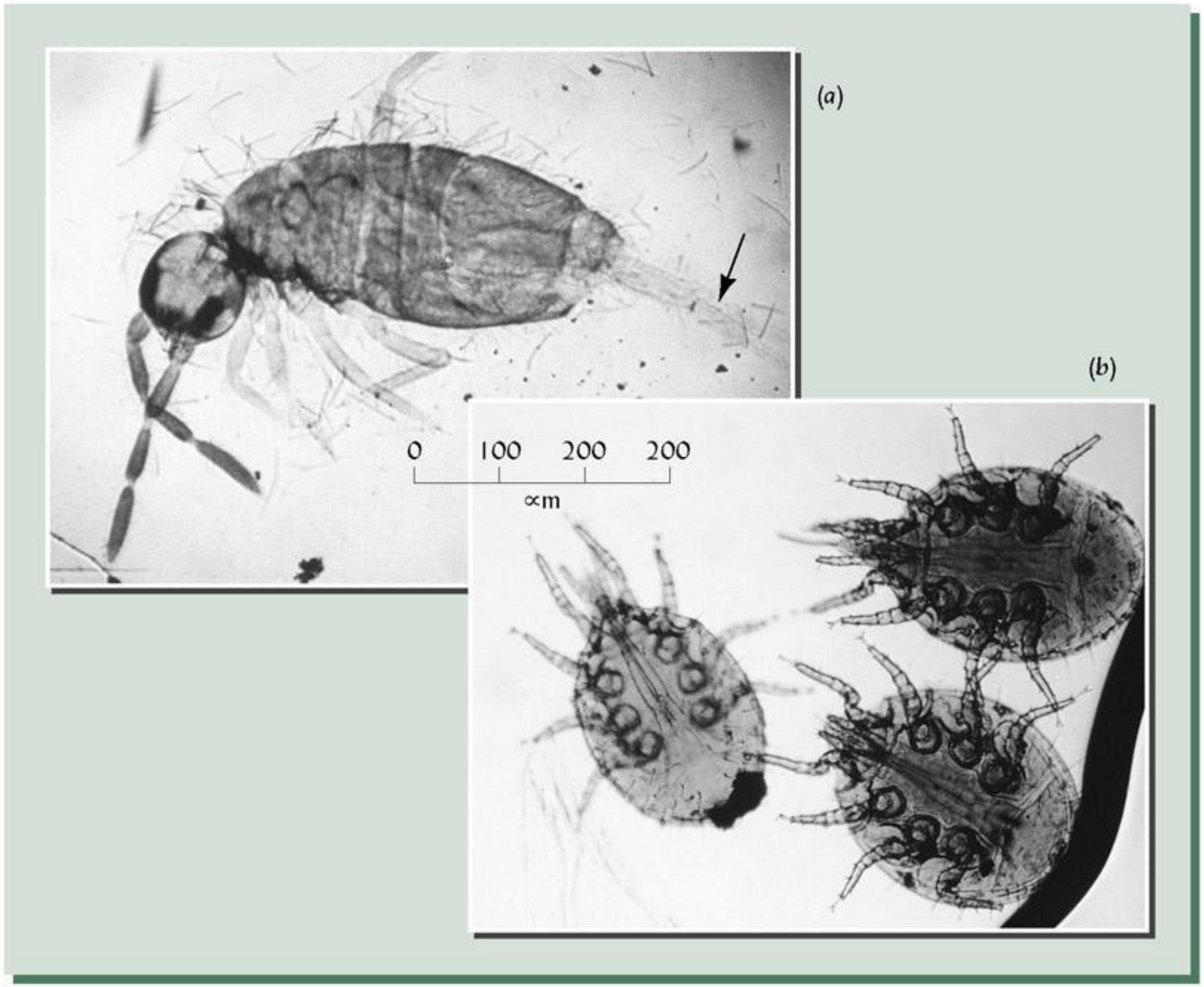


TABLE 11.4 Relative Numbers and Biomass of Fauna and Flora Commonly Found in the Surface 15 cm of Soil[a]

Since metabolic activity is generally related to biomass, microflora and earthworms dominate the life of most soils.

	Number		*Biomass*[b]	
Organisms	*Per m²*	*Per gram*	*kg/ha*	*g/m²*
Microflora				
Bacteria	10^{13}–10^{14}	10^{8}–10^{9}	400–5000	40–500
Actinomycetes	10^{12}–10^{13}	10^{7}–10^{8}	400–5000	40–500
Fungi	10^{10}–10^{11}	10^{5}–10^{6}	1,000–15,000	100–1500
Algae	10^{9}–10^{10}	10^{4}–10^{5}	10–500	1–50
Fauna				
Protozoa	10^{9}–10^{10}	10^{4}–10^{5}	20–200	2–20
Nematodes	10^{6}–10^{7}	10–10^{2}	10–150	1–15
Mites	10^{3}–10^{6}	1–10	5–150	.5–1.5
Collembola	10^{3}–10^{6}	1–10	5–150	.5–1.5
Earthworms	10–10^{3}		100–1500	10–150
Other fauna	10^{2}–10^{4}		10–100	1–10

[a] A greater depth is used for earthworms.
[b] Biomass values are on a liveweight basis. Dry weights are about 20 to 25% of these values.

Figure 11.4

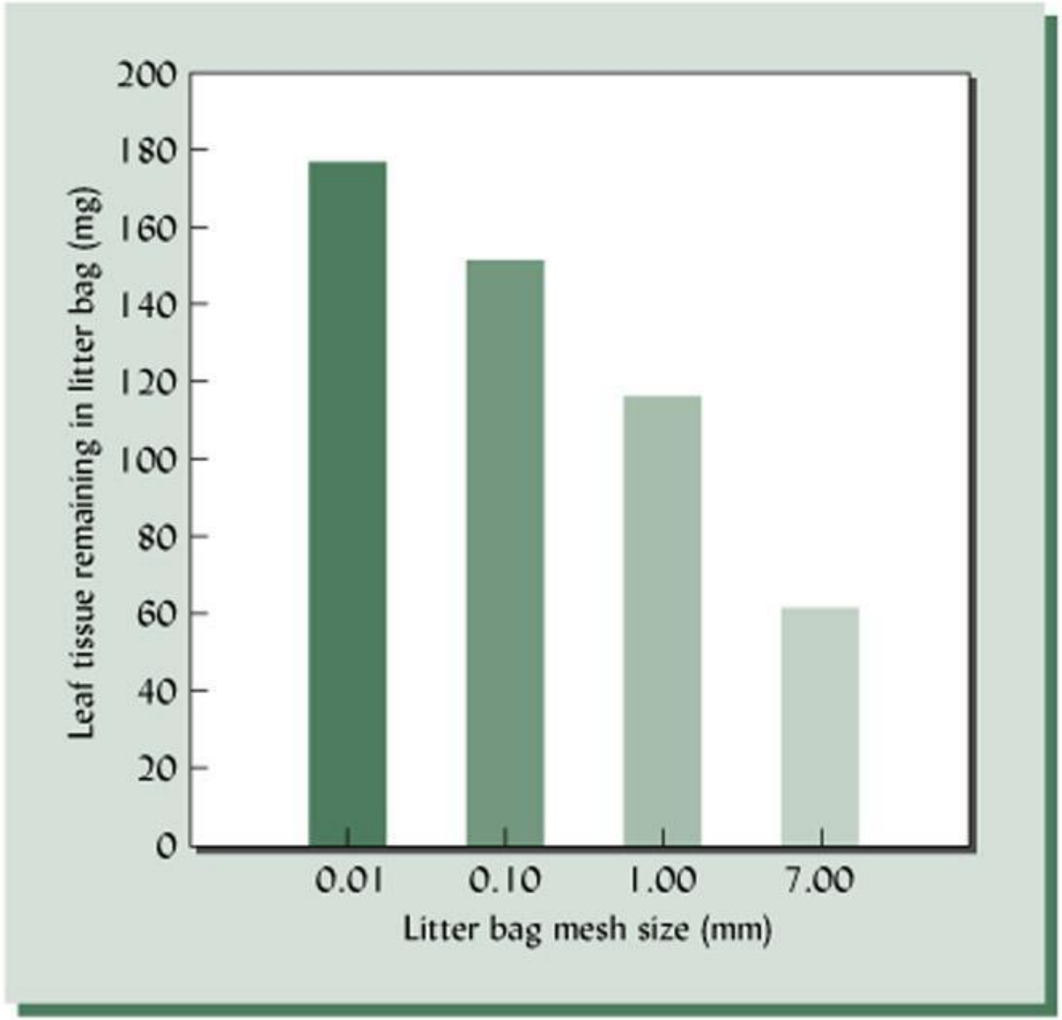

200
180
160
140
120
100
80
60
40
20
0
Leaf tissue remaining in litter bag (mg)
0.01
0.10
1.00
7.00
Litter bag mesh size (mm)

Figure 11.5

Earthworms

- Earthworms eat detritus, soil organisms matter, and microorganisms found on these materials.
  - Probably the most significant macroorganisms in humid temperate region soils
  - 7000 species worldwide
  - Epigeic – Live in the litter layer. The compost worm (*Eisenia foetida*)
  - Endogeic – Live in the top 10-30cm of soil. The pale-pink “red worm” (*Allolobophora caliginosa*)
  - Anecic – Live in vertical burrows up to 1 meter deep. The introduced

Figure 11.6

Soil Aeration by Earthworms

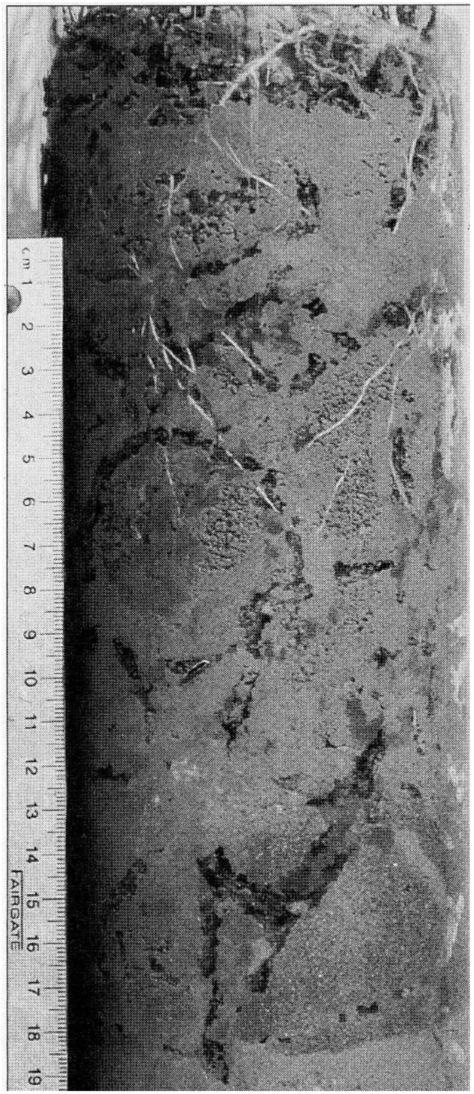


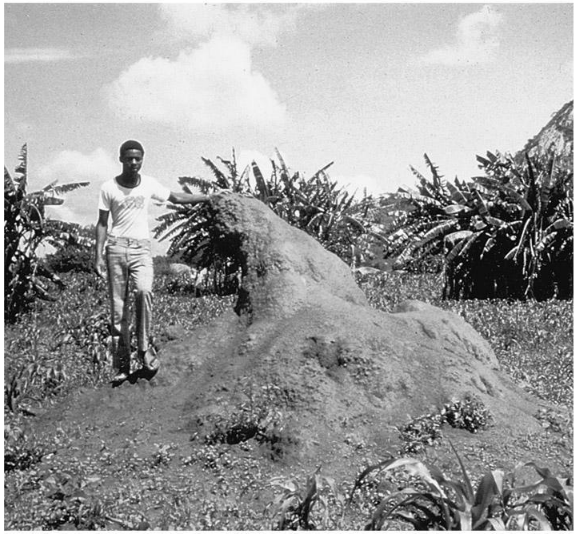
TABLE 11.7 Improvements in Soil Ecosystem Quality Nine Years After Inoculating Restored Coal-Mine Land with Earthworms

Earthworms were initially absent from the soils being restored. The mine site in Wales (U.K.) was covered with clay loam surface horizon material that had been pushed aside and stored for four months during the coal-mining operation. Earthworms of several indigenous species were added (70/m^2) to certain experimental plots, but not to the control plots. Without inoculation, normal populations of earthworms may take 20 to 30 years to recolonize such soils.

	Earthworm population,[a] *number/m^2*	*Carbohydrate content in soil,*[b] *g/100 g soil*	*Clay dispersed by wetting soil,*[c] *g/100 g soil*	*Metabolic quotient,*[d] *mg CO_2-C g^{-1} h^{-1}*
Control (no earthworms added)	8	0.90	23.7	15.3
Earthworms added	106	1.28	16.9	10.9
Percent change	+1200	+42	–29	–29

[a] Earthworm populations were measured 6 years after restoration began.
[b] Carbohydrates were mainly polysaccharides, which may have been produced by the earthworms themselves or by bacteria stimulated by the earthworms.
[c] Clay dispersed when dry soil aggregates are shaken in water is a measure of the stability of the aggregate structure and the soil's resistance to erosion. More dispersed clay indicates weaker structure.
[d] Metabolic quotient is the amount of respiration occurring per g of microbial biomass. A higher value indicates a stressed ecosystem in which microorganisms must devote increased energy to survival rather than growth. The units are mg of C respired in the form of CO_2 per g of microbial biomass per hour. See also Table 20.11. Data from Scullen and Malik (2000).

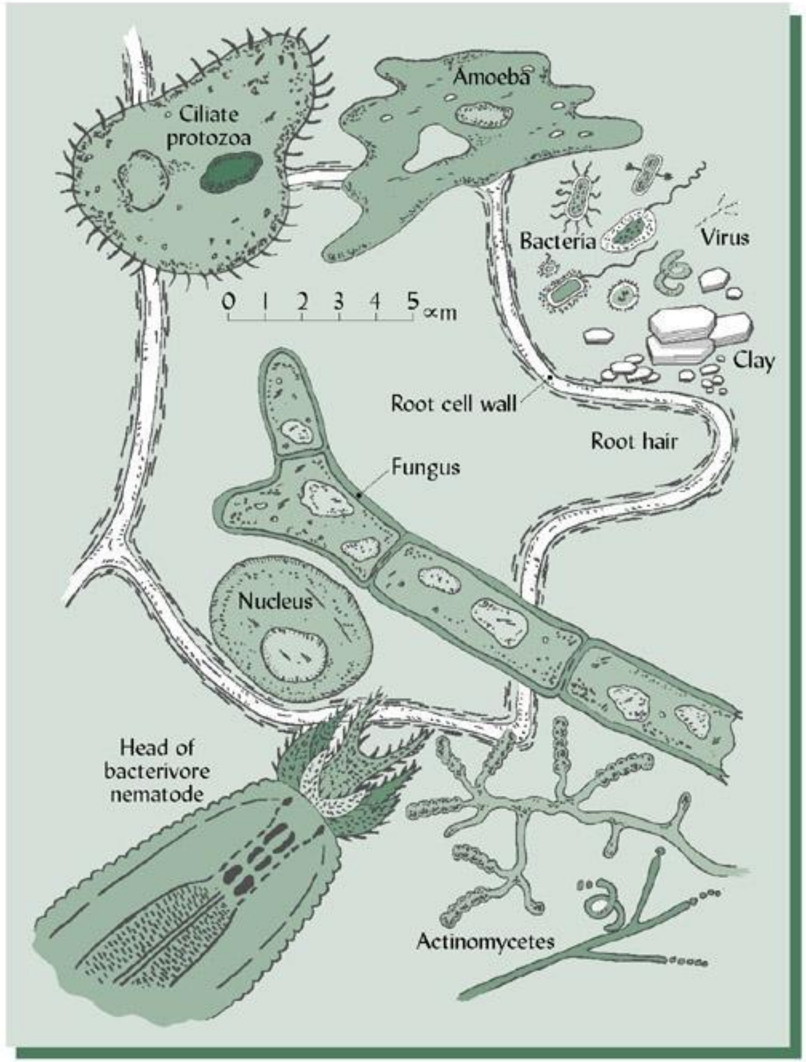
Figure 11.9



Termite

Figure 11.10

Figure 11.12


Amoeba
Ciliate protozoa
Bacteria
Virus
0 1 2 3 4 5 μm
Clay
Root cell wall
Root hair
Fungus
Nucleus
Head of bacterivore nematode
Actinomycetes

Nematode

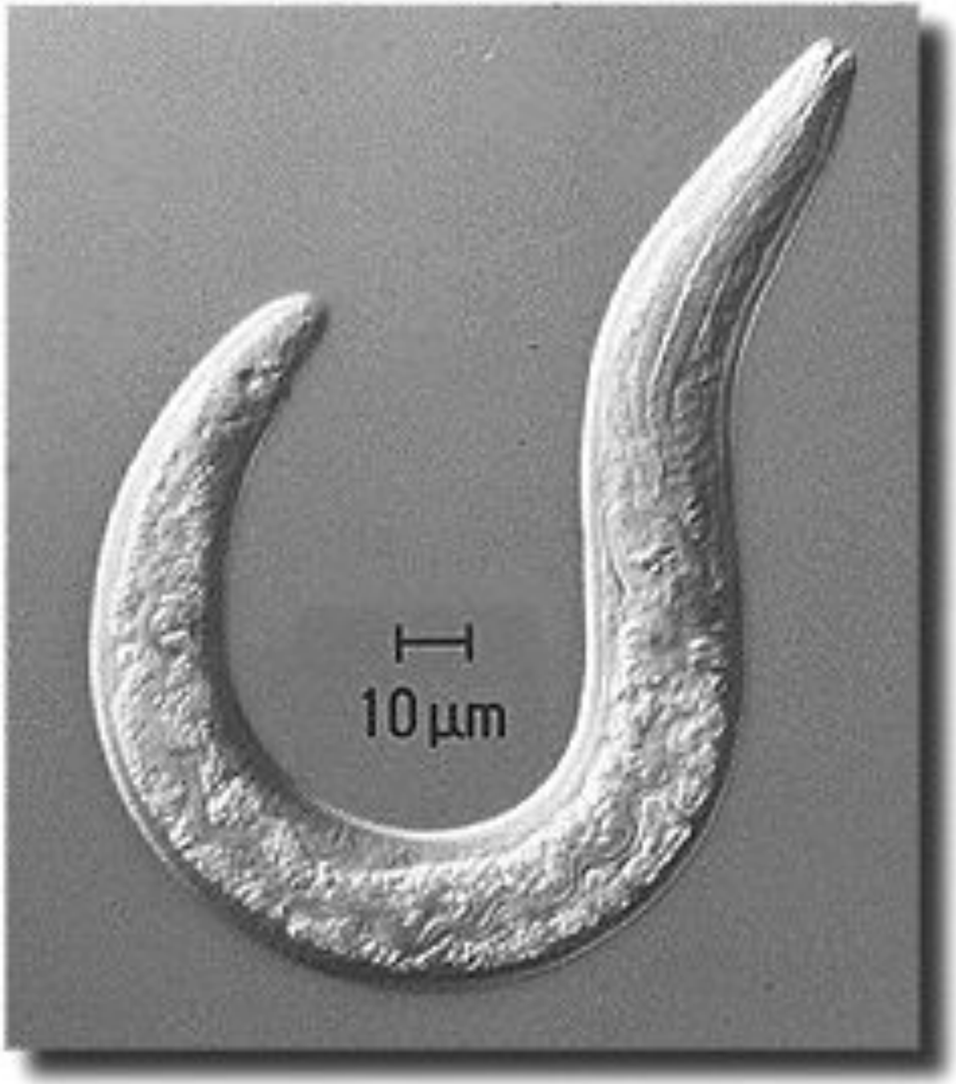
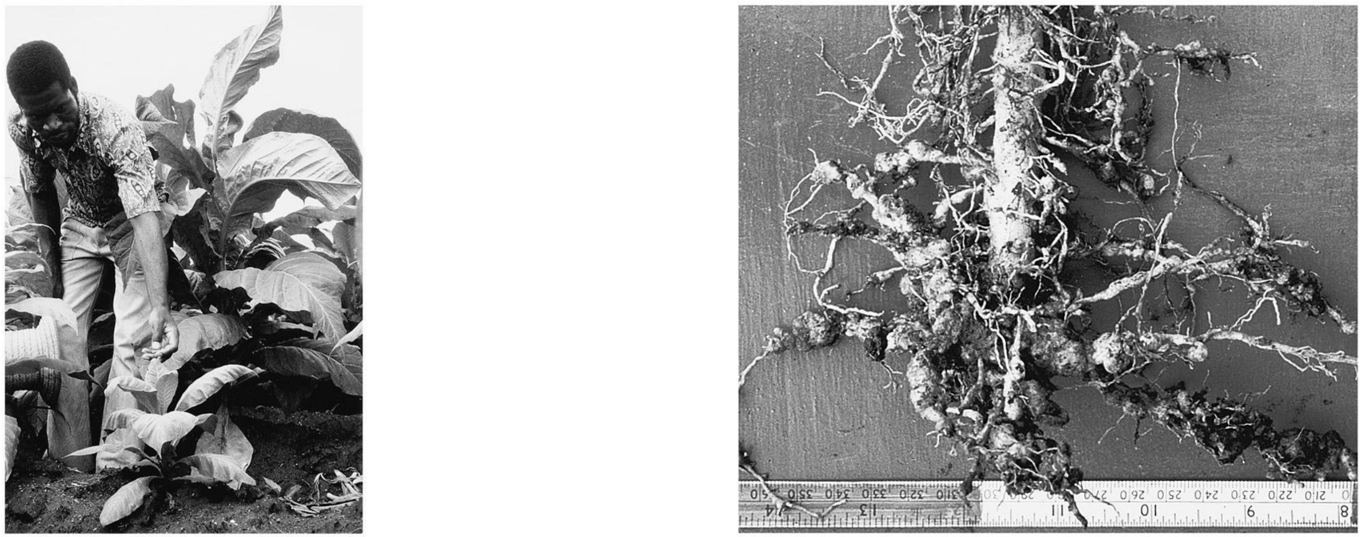
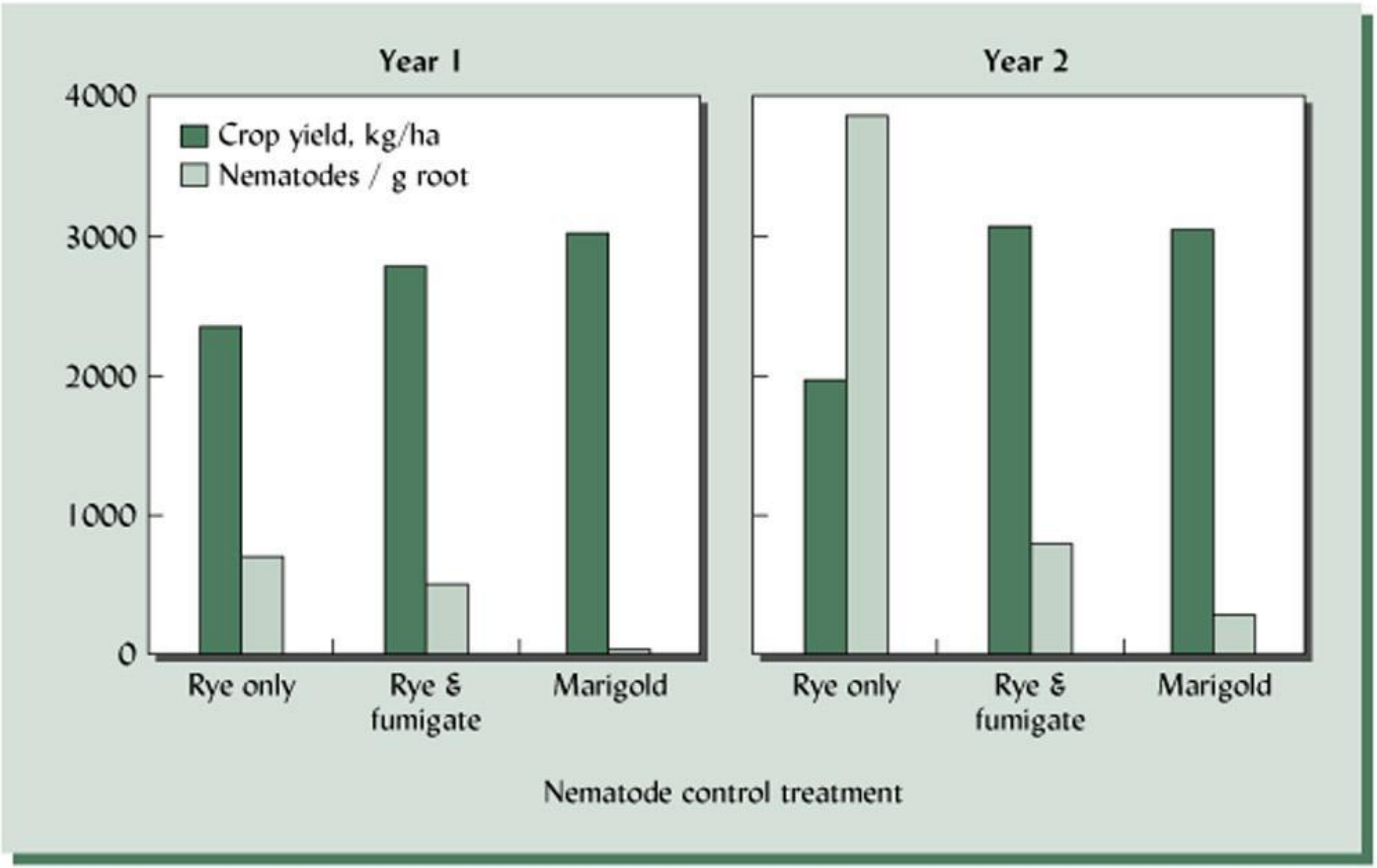


Figure 11.13



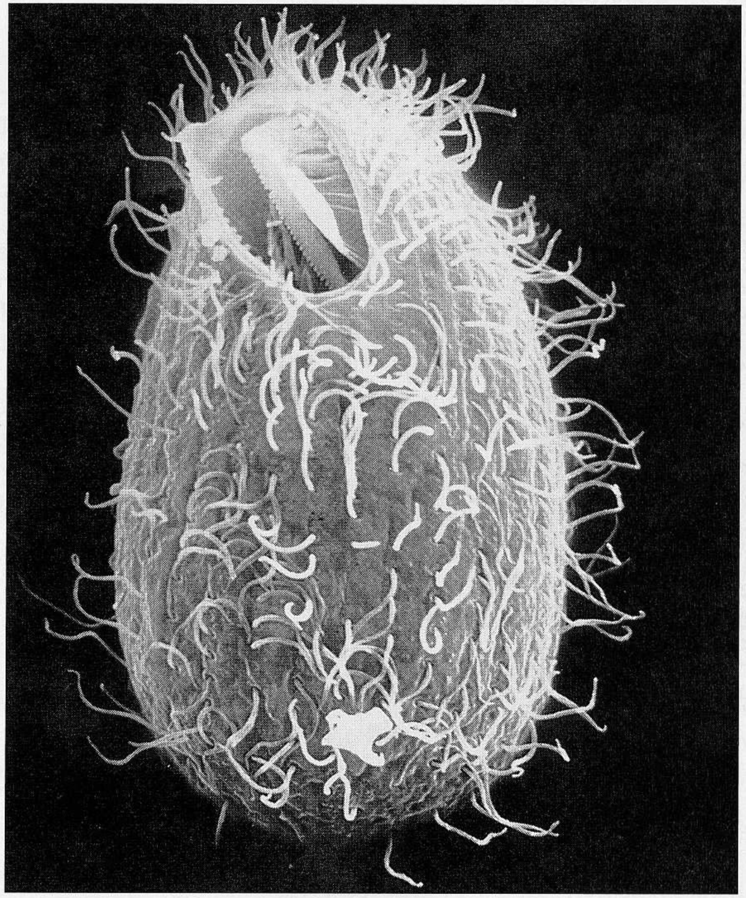
(a) (b)

Figure 11.14

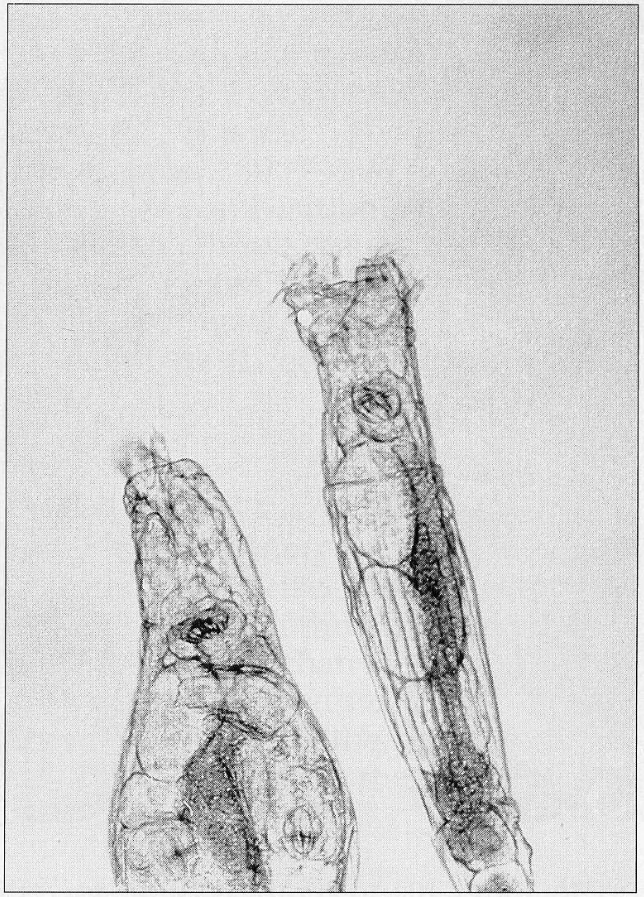


Year 1
Year 2
Crop yield, kg/ha
Nematodes / g root
4000
3000
2000
1000
0
Rye only
Rye & fumigate
Marigold
Rye only
Rye & fumigate
Marigold
Nematode control treatment

Two Microanimals Typically Found in Soils



Ciliated protozoan



Two species of rotifer

THE NATURE AND PROPERTIES OF SOILS, 13/e
Nyle C. Brady and Ray R. Weil

Roots and Rhizosphere

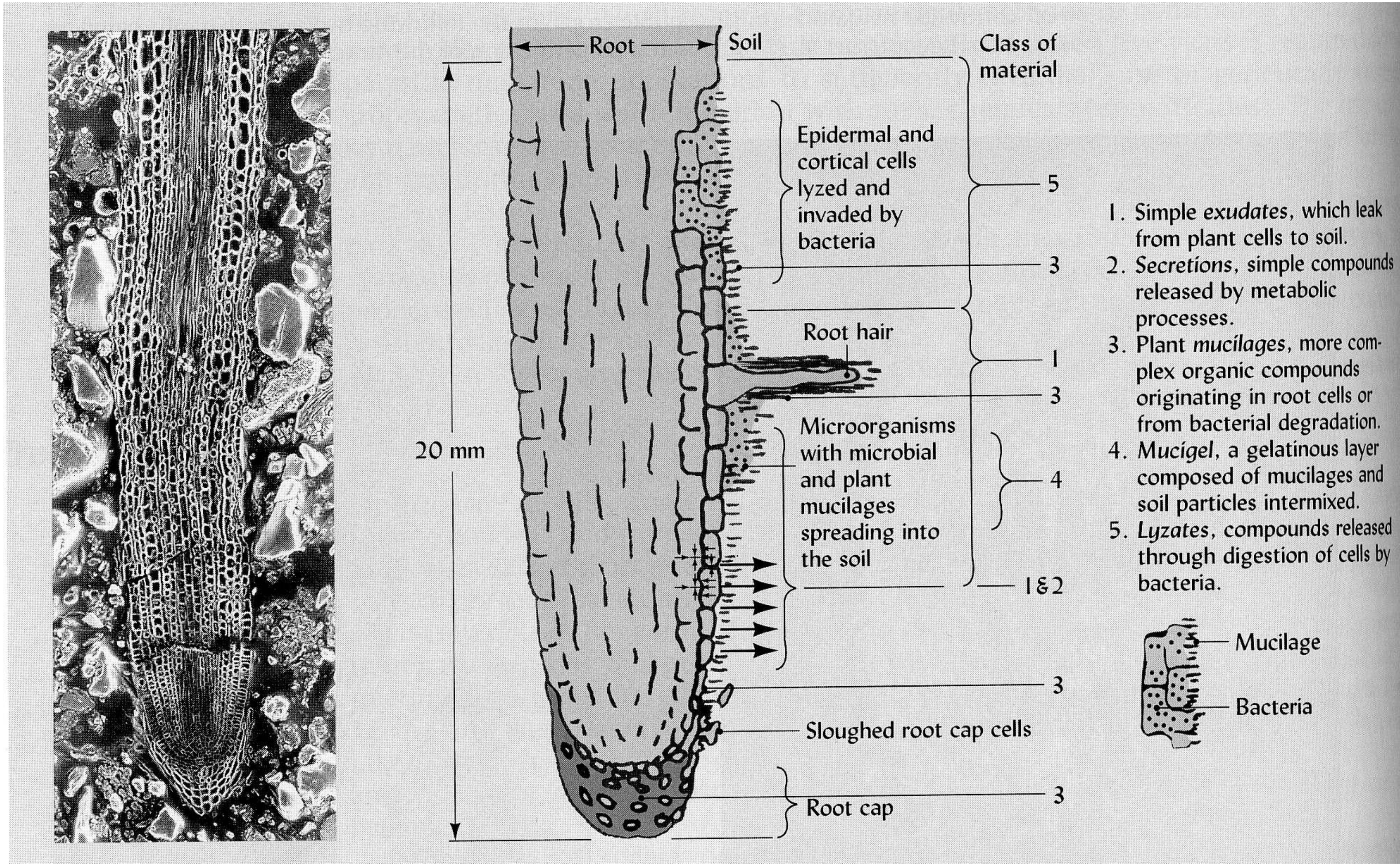
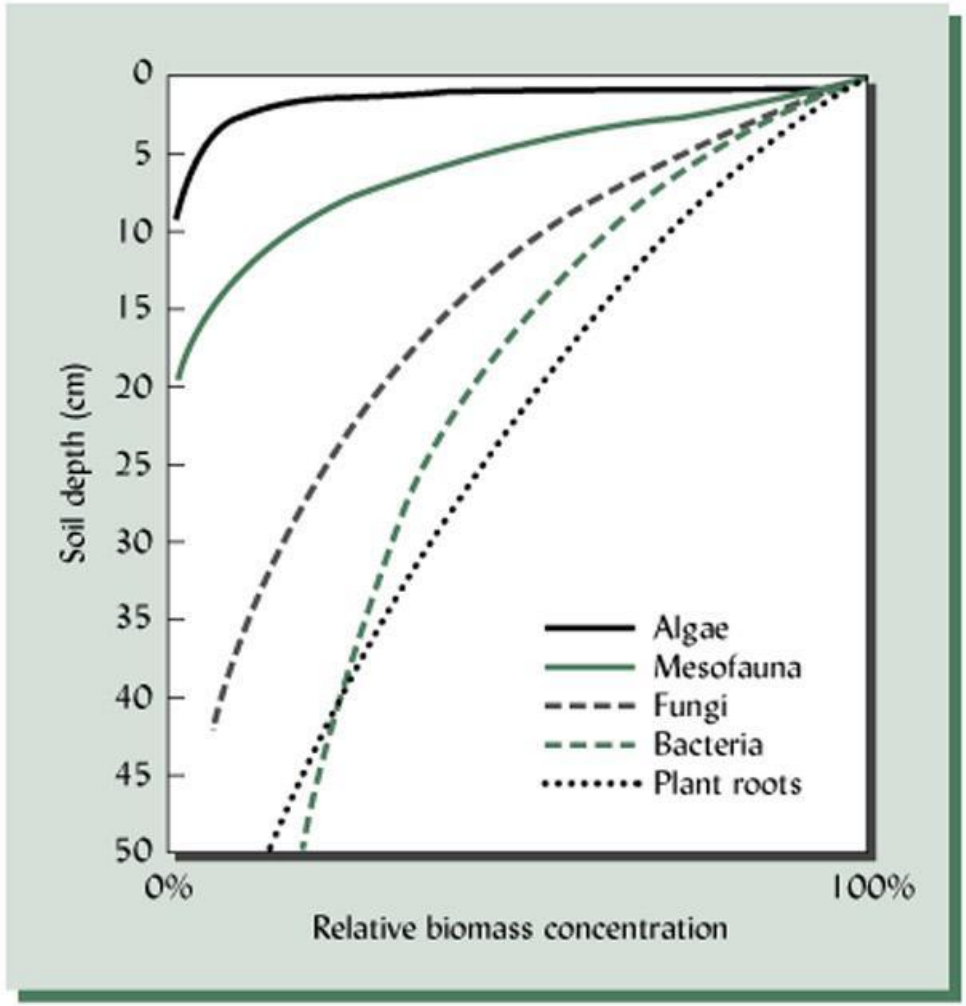


Figure 11.17

Figure 11.18



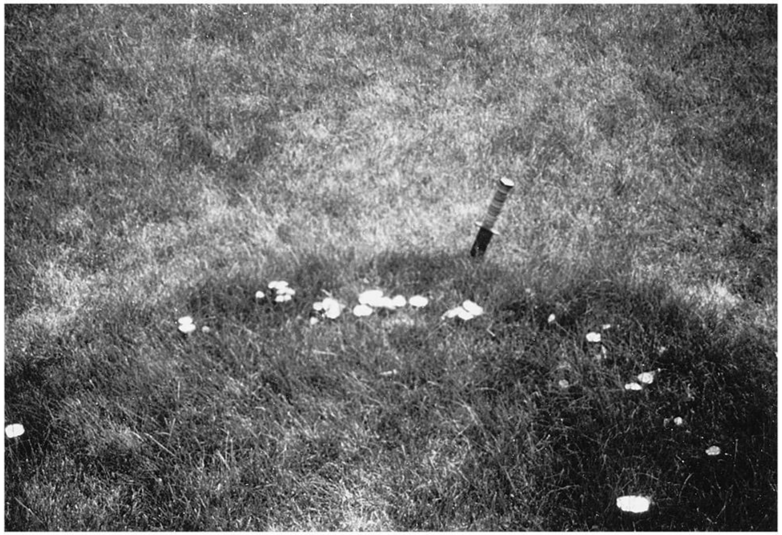
0
5
10
15
20
25
30
35
40
45
50
Soil depth (cm)
Algae
Mesofauna
Fungi
Bacteria
Plant roots
0%
100%
Relative biomass concentration

Figure 11.1[illegible]

Figure 11.20

Figure 11.21

(a)



(b)

Figure 11.22

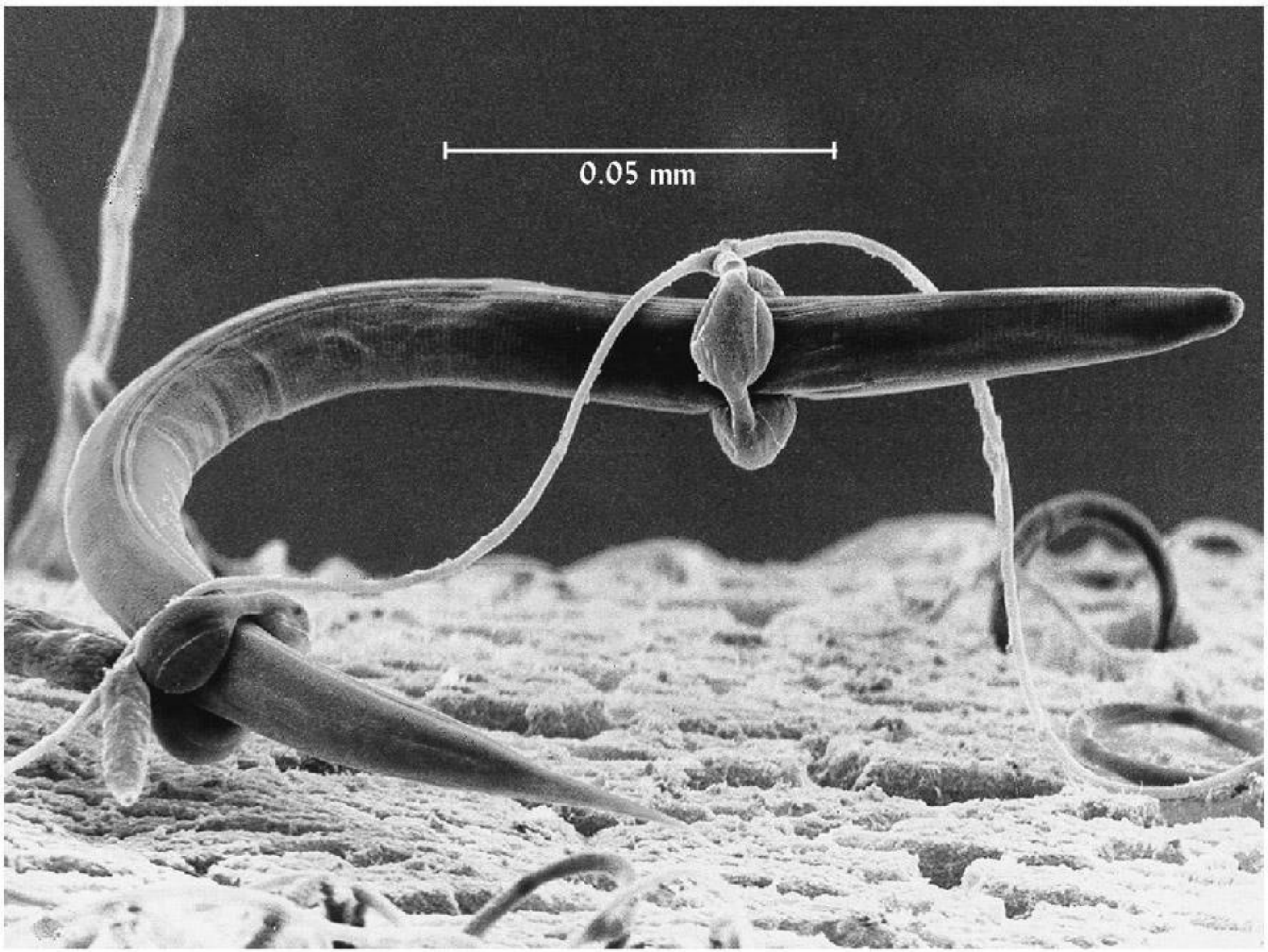
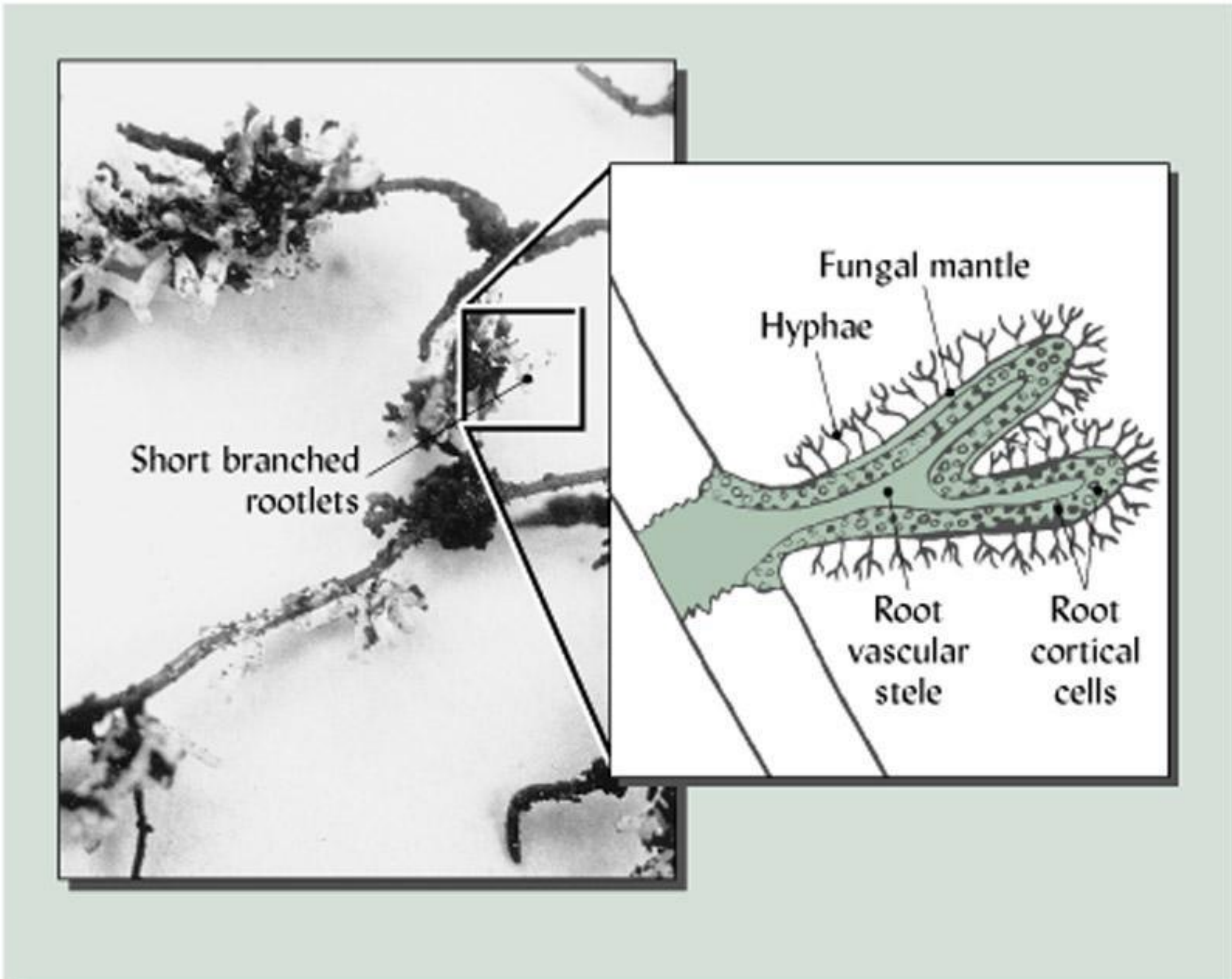


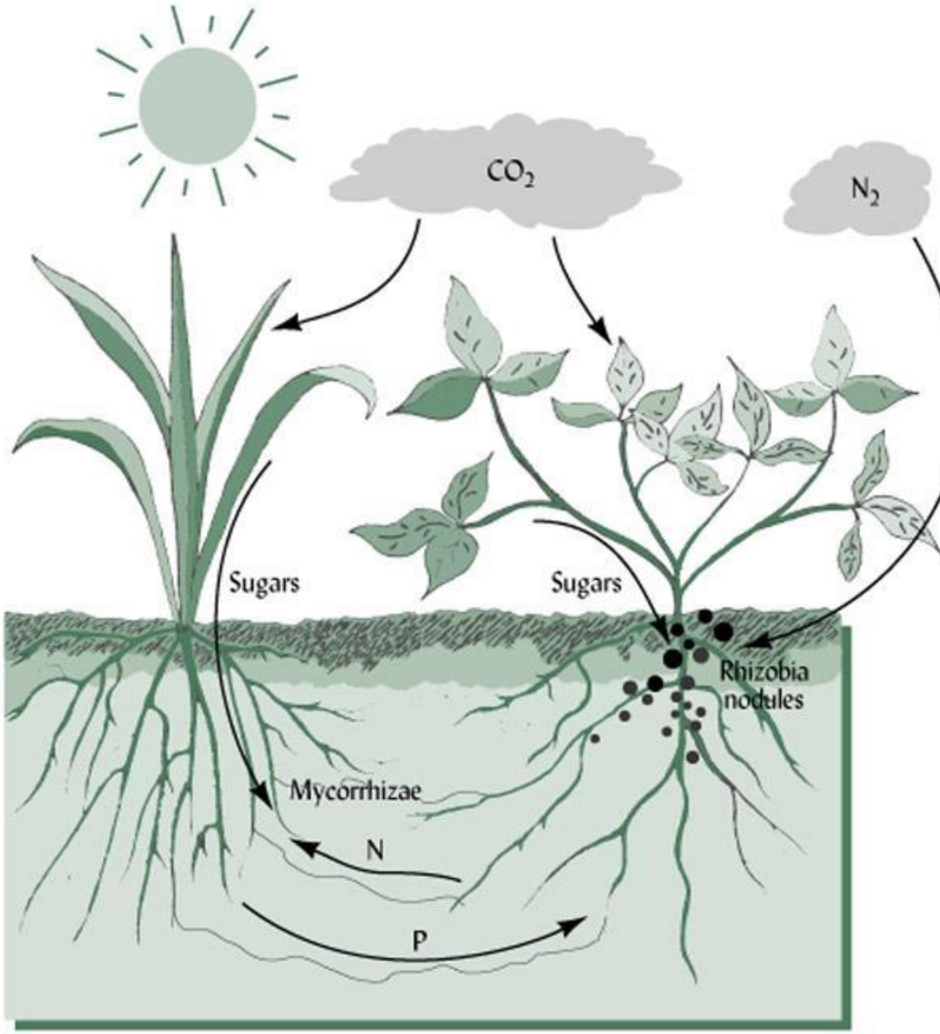
Figure 11.23



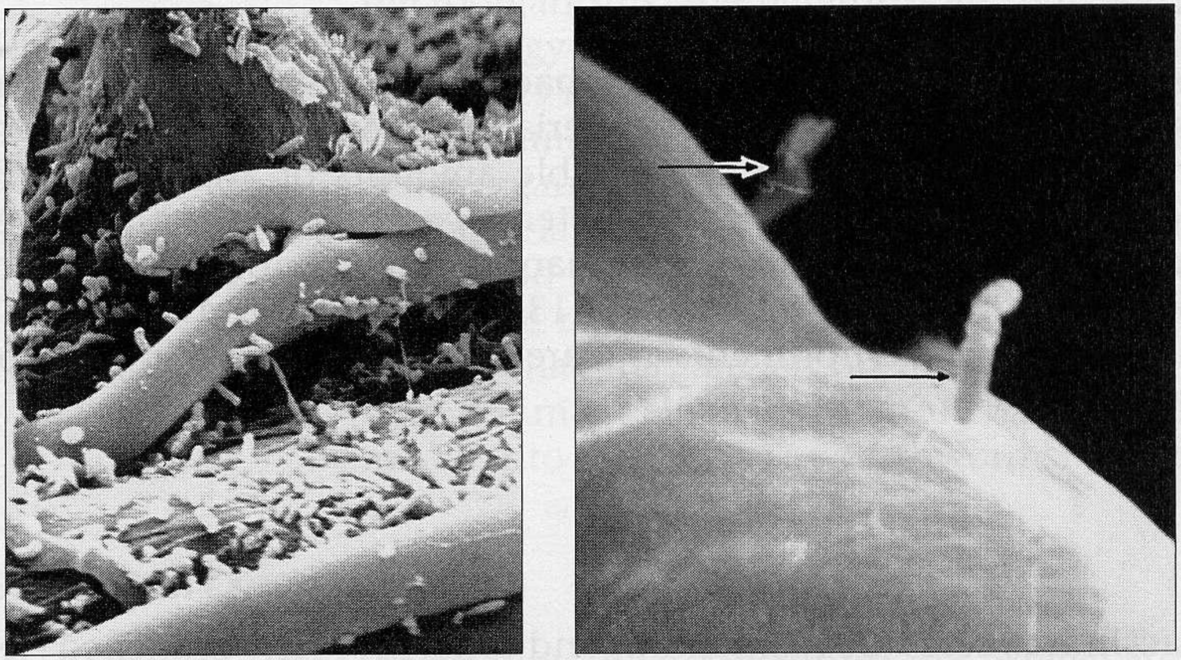
Short branched rootlets
Fungal mantle
Hyphae
Root vascular stele
Root cortical cells

The Effect of Phosphorous and Mycorrhizae Treatments

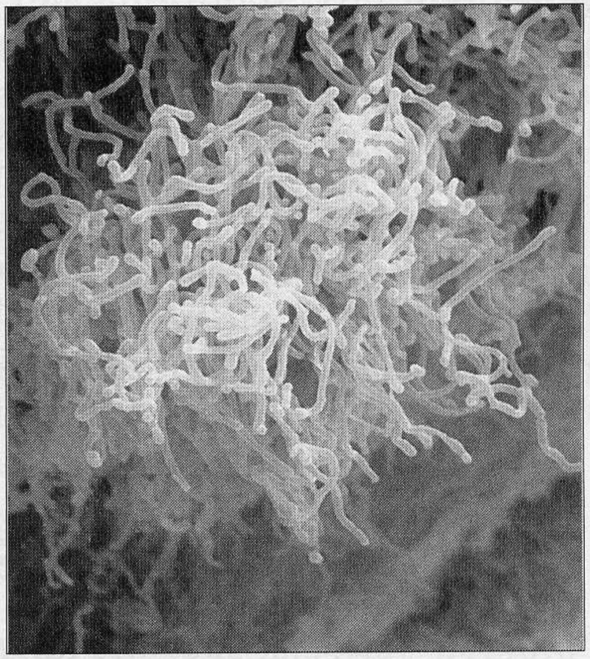
Figure 11.25



Fungi, Bacteria, and Actinomycetes



Fungal Hyphae and rod-shaped bacteria



Actinomycete threads

Figure 11.31

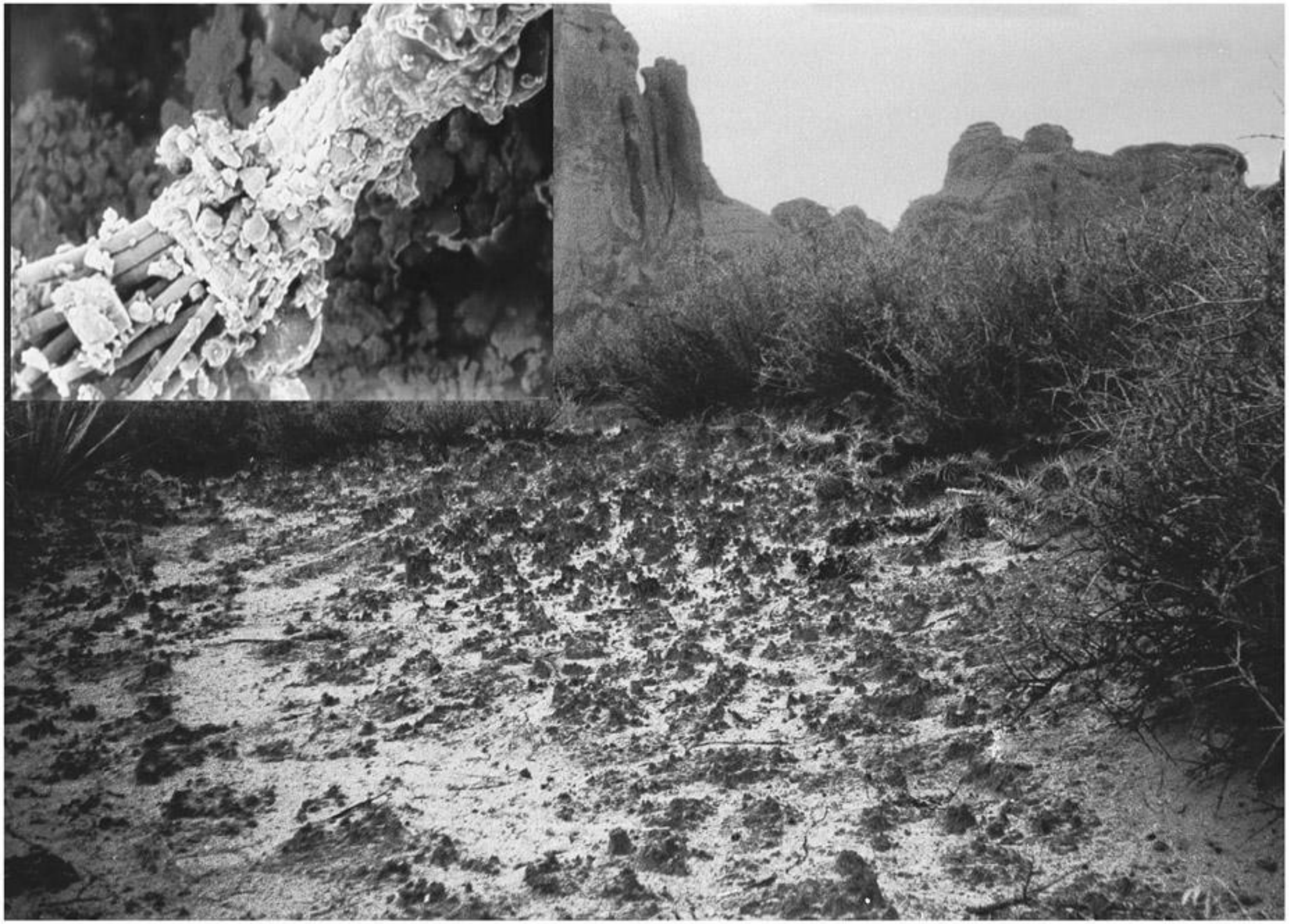


Figure 11.24

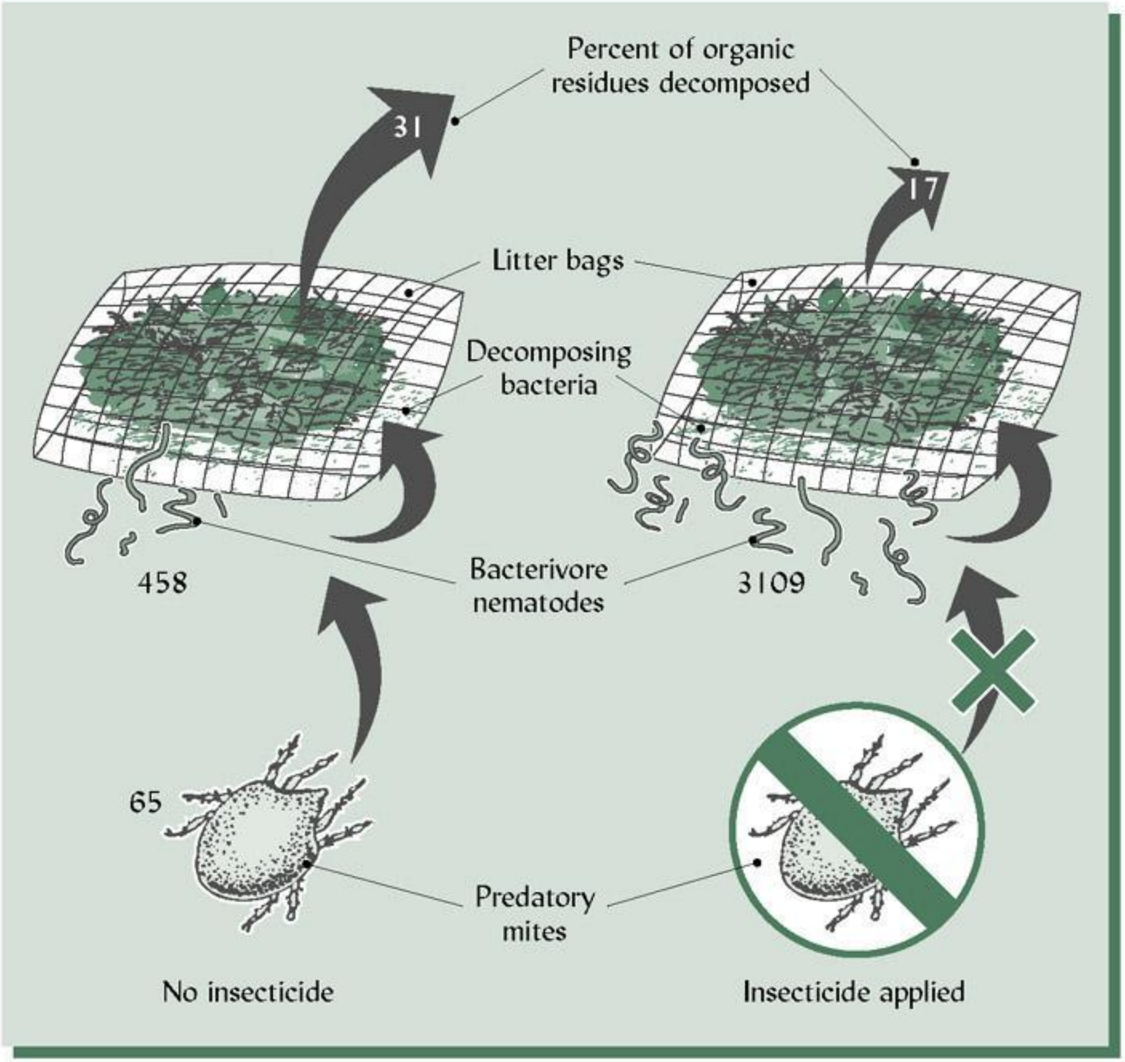

Percent of organic residues decomposed
31
17
Litter bags
Decomposing bacteria
458
3109
Bacterivore nematodes
65
Predatory mites
No insecticide
Insecticide applied

TABLE 11.10 The Generalized Effects of Major Soil-Management Practices on the Overall Diversity and Abundance of Soil Organisms

Note that the practices that tend to enhance biological diversity and activity in soils are also those associated with efforts to make agricultural systems more sustainable.

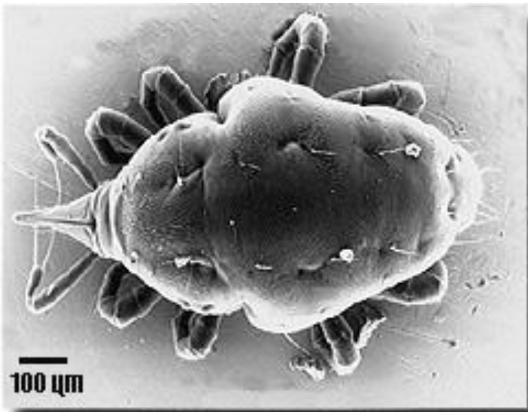
Decreases biodiversity and populations	*Increases biodiversity and populations*
Fumigants	Balanced fertilizer use
Nematicides	Lime on acid soils
Some insecticides	Proper irrigation
Compaction	Improved drainage and aeration
Soil erosion	Animal manures and composts
Industrial wastes and heavy metals	Domestic (clean) sewage sludge
Moldboard plow–harrow tillage	Reduced or zero tillage
Monocropping	Crop rotations
Row crops	Grass–legume pastures
Bare fallows	Cover crops or mulch fallows
Residue burning or removal	Residue return to soil surface
Plastic mulches	Organic mulches

TABLE 11.11 Effect of Tillage Systems on Biomass Carbon of Microbial and Faunal Groups in Soil

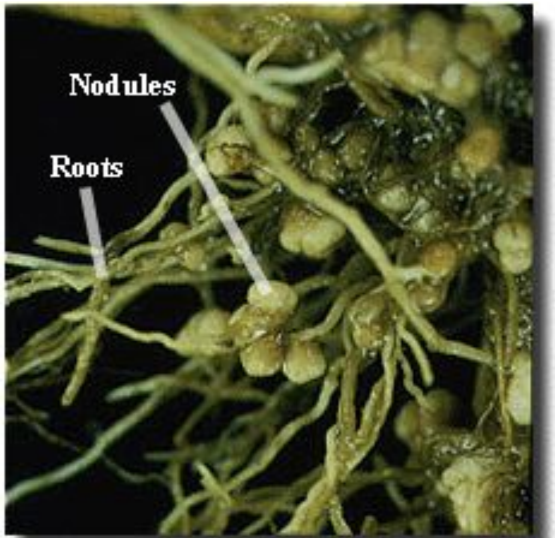
Researchers in Georgia grew grain sorghum in summer and a rye cover crop each winter on a sandy loam (Kanhapludults). With plow tillage, plant residues were mixed into the soil, but with no-tillage residues were left as surface mulch. Decomposer, microphytic feeder, and detritivore functions were dominated by larger organisms (fungi, microarthropods, and earthworms) in the no-till system, while smaller organisms (bacteria, protozoa, nematodes, and enchytraeid worms) were more prominent in the plowed system.

	Carbon, kg/ha							
				Nematodes[b]				
Tillage	*Fungi*[a]	*Bacteria*[a]	*Protozoa*[b]	*Fungivores*	*Bacterivores*	*Microarthropods*[a]	*Enchytraeids*[c]	*Earthworms*[c]
No-till	360	260	24	0.14	0.82	1.31	5.55	60
Plowed	240	270	39	0.47	1.27	0.49	4.79	21

[a] 0 to 5 cm depth.
[b] 0 to 21 cm depth.
[c] 0 to 15 cm depth.
Calculated from data of various sources presented by Beare (1997).


100 µm


Springtail


Nodules
Roots