

Unit 7: Symbiotic associations

**Lichen
&
Mycorrhiza**

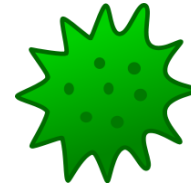
WHAT IS A LICHEN?

- o Lichens are made up of two different organisms **living together**:

A **fungus**



and an **alga**



.



- o The **fungus** provides the body in which the alga can live protected from light and drought.

- o **Mycobiont** – the fungal partner in a lichen.



- o The **alga** makes the food for the fungus.
- o **Photobiont** – the photosynthetic partner in a lichen; either a green alga or cyanobacterium.

Symbiotic association

- Traditionally been classified as a mutualistic symbiosis where both symbionts benefit
- Fungus appears to be chief benefactor, receives
 - Organic compounds as C and energy source
 - With cyanobacteria, N fixation may occur so that the fungus also receives N source

Symbiotic association

- Benefits for autotrophic symbiont are less clear-cut
 - Fungus produces substances that absorb water which is provided to alga
 - Fungus takes up inorganic nutrients from atmosphere
 - Protects algal cells from mechanical injury, predation, and high light intensities
 - Association allows alga to achieve a wider distribution than if free-living

Symbiotic association

- *Trebouxia* is not very successful as a free-living alga
- Alga pays a high price for these benefits
- Lichen might be a better example of controlled parasitism than mutualism
- Lichens are long term, close symbioses
- Together the organisms express different characteristics than individually

Symbiotic association

- Sexual reproduction by fungus only occurs in the association
- A number of chemicals are only synthesized by the symbiosis – dyes, antibiotics, essential oils, litmus (over 600 different chemicals unique to lichens have been identified)



Occurrence

- One of the most successful mutualistic associations in the world.
- Over 13,500 species based on the mycobiont.
- Early inhabitants of the harsh environments of the Silurian and Devonian.
- Worldwide distribution, often in the most extreme environments, Arctic, Antarctic, deserts and all other habitats.

General characteristics

- Primary colonizers in primary succession.
- Occur on soil, plants, animals, rocks, decorate tombstones, buildings, etc.
- Rare in polluted areas - intolerant of industrial pollutants, especially sulfur dioxide.
- Slow growing - most 1 mm/yr, a few up to 4 mm/yr.
- Growth favored by high humidity, cool temperatures & low light.
- Long-lived - Alpine-arctic lichens may be 1000-4500 yrs old.
- Longevity attributed to ability to withstand long periods of drought and resume growth when water becomes available.

Range of thallus organization

- Dust/leprose - Lack both upper & lower cortex, medulla attached directly to substrate.
- Crustose - Lack a lower cortex, attached directly to the substrate by medullary hyphae.
- Squamulose - Lack a lower cortex, composed of scale-like segments, often forming erect podetia.
- Foliose - Flattened, leaf-like thalli with an upper and lower cortex, often with rhizines.
- Fruticose - Strap or thread like, often attached to substrate by holdfast.

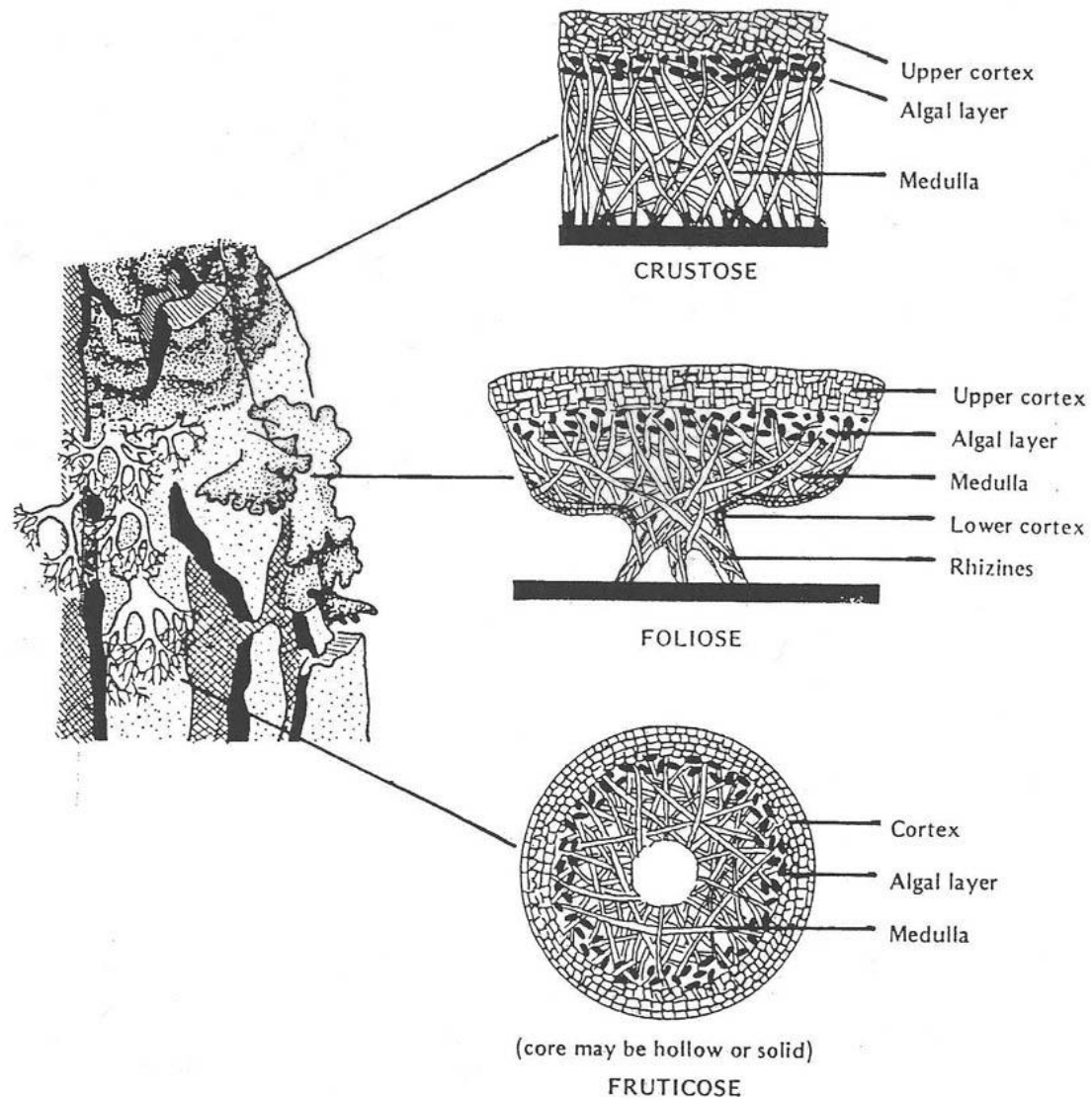
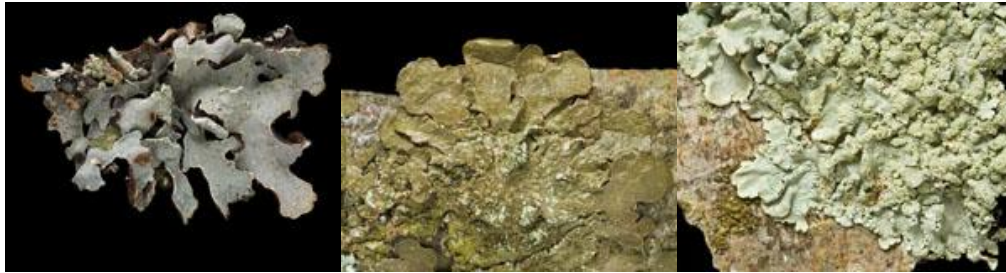


Fig. 2. Three main types of lichen thalli (i.e., crustose, foliose, and fruticose, and their different layers). [From Ahmadjian and Paracer, 1986. University Press of New England.]

Range of thallus organization (What do lichens look like?)



- Leafy lichens



Parmelia family – brown, yellow-green and grey-green leafy lichens – have short hairs on their underside



Xanthoria – orange leafy lichens

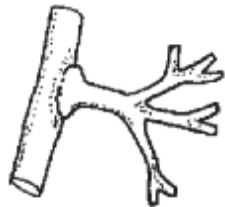


Physcia – with longish hairs on the edges

- Bushy lichens



Evernia - Green top & White underside



Usnea – like a wirey beard



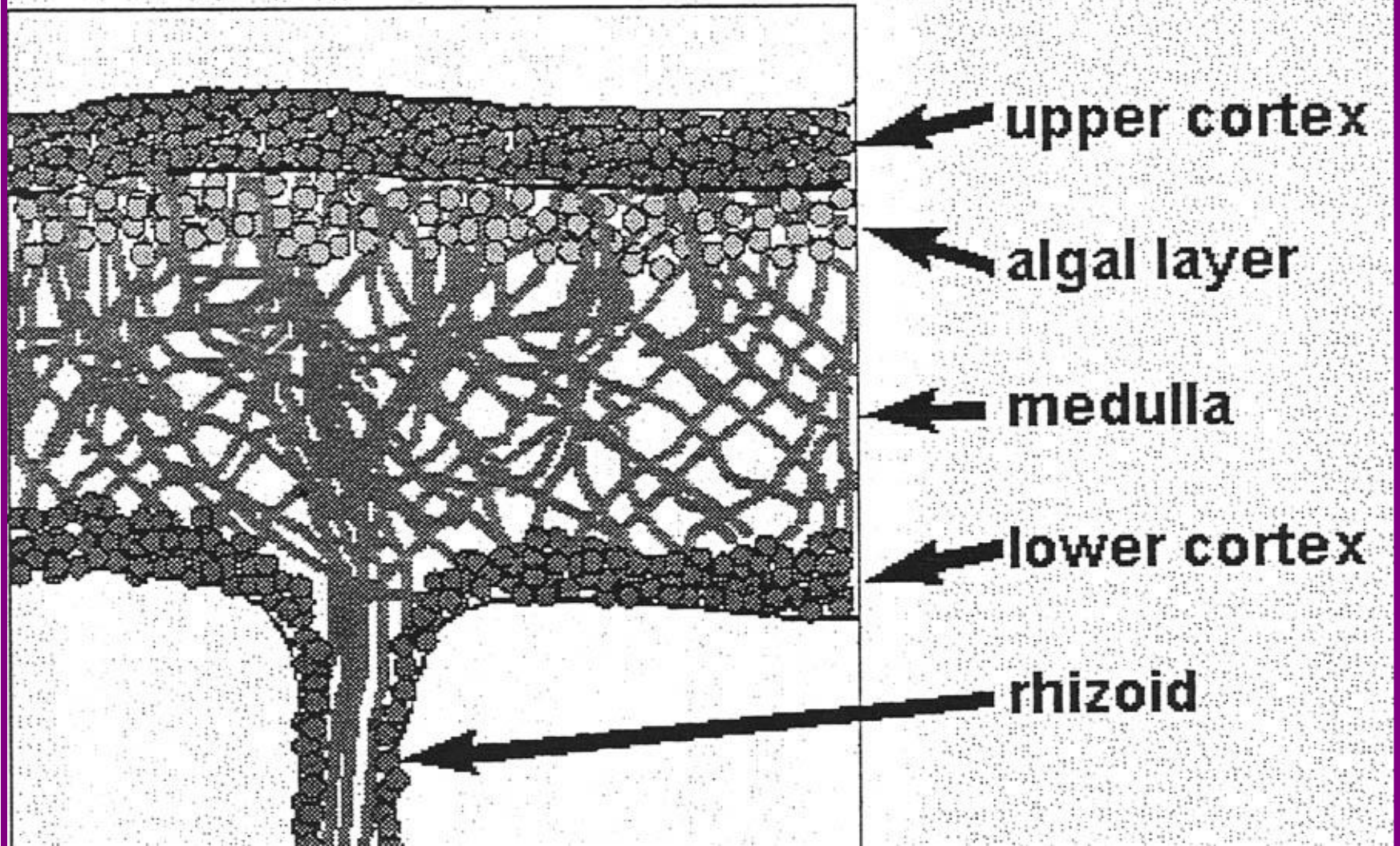
Hypogymnia – a puffy lichen with no hairs

Range of thallus organization

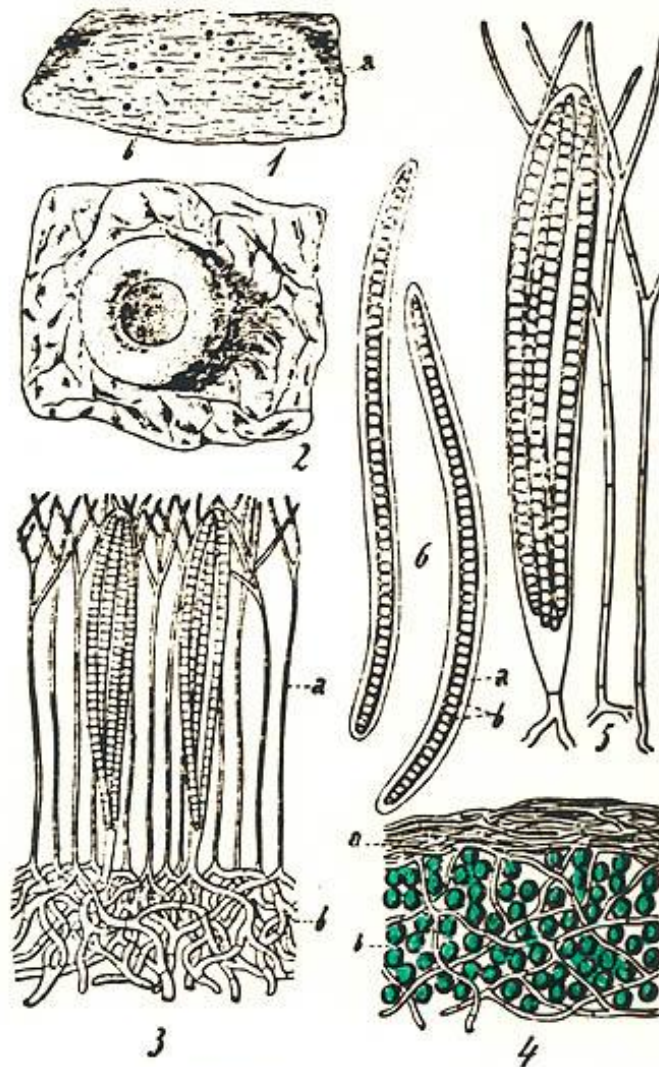
- Are composite organisms that have a different morphological appearance than either of the symbionts.
- Consist of a
 - Cortex (upper and/or lower).
 - Medulla (fungal layer).
 - Algal layer.
- Stratified - differentiated into cortex (upper and/or lower) and medulla with the photobiont cells forming a discrete layer.
- Non-stratified - photobiont cells evenly distributed throughout thallus.

Anatomy of Lichens

Structure of a Lichen



Non-stratified, algal cells distributed throughout.



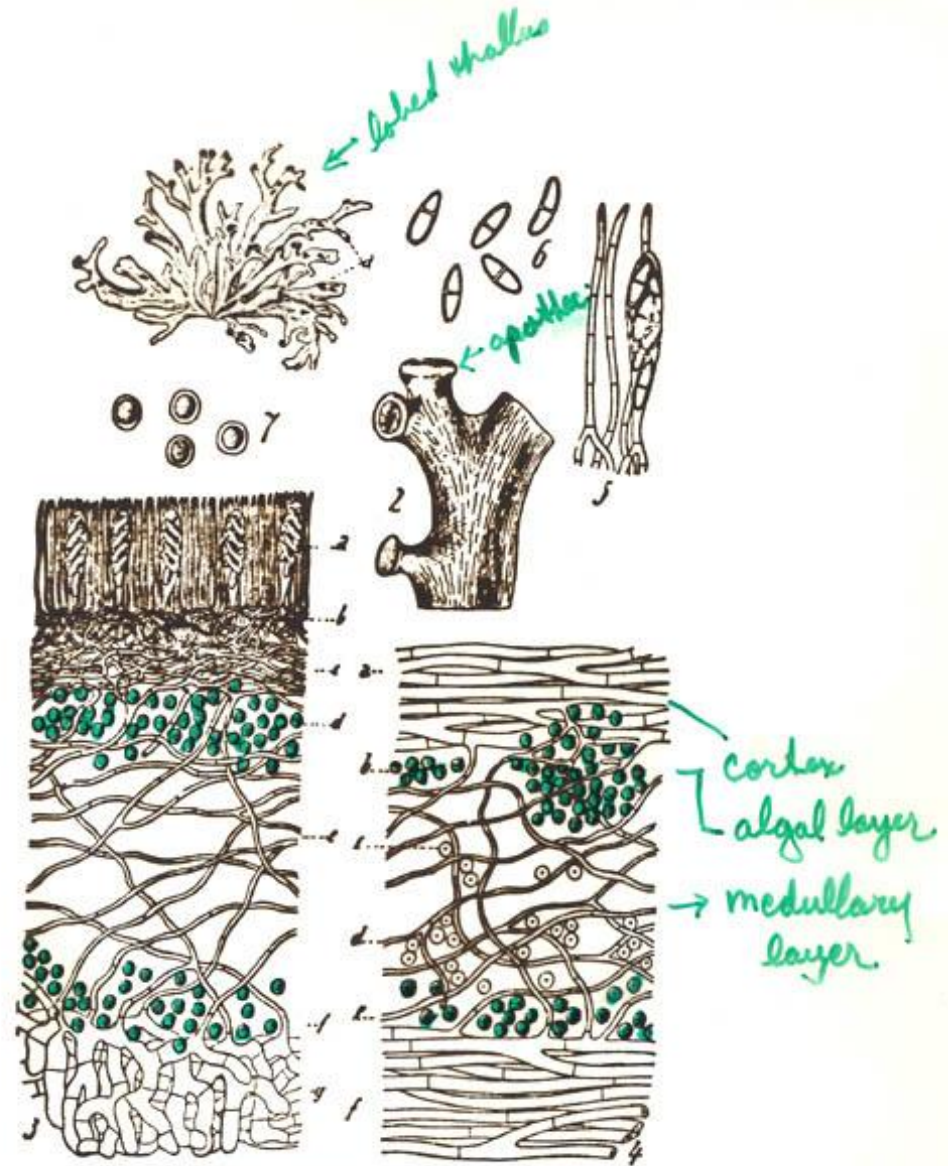
CONOTREMA URCEOLATUM (ACH.) TUCK.

Fig. 1, a, an apothecium; b, the thallus. Fig. 2, an apothecium and a portion of the thallus. Fig. 3, a section of an apothecium; a, the hymenium; b, the hypothecium. Fig. 4, a section of the thallus; a, the pseudocortex of entangled hyphae; b, the layer of algal cells and hyphae below. Fig. 5, paraphyses and an ascus. Fig. 6, free spores transversely septate; a, the endospore; b, the cell lumina. Fig. 1, natural size; fig. 2, enlarged about 20 diameters; figs. 3, 4, enlarged about 400 diameters; figs. 5, 6, enlarged 650 diameters. From Schneider.

} pseudocortex
} algal cells
+ hyphae

homiomorous

Stratified lichen.



RAMALINA CALICARIS (L.) E. FRIES

Fig. 1, the plant, showing the lobed thallus and the apothecia. Fig. 2, a portion of the thallus and three apothecia. Fig. 3, a section through an apothecium and the thallus below: *a*, the hymenium; *b* and *c*, the hypothecium; *d*, the algal layer; *e*, the medullary layer; *f*, the algal layer; *g*, the pseudocortex of entangled hyphae. Fig. 4, a longitudinal section of the thallus; *s* and *f*, the pseudocortex; *b* and *c*, the algal layer; *e* and *d*, the medullary layer. Fig. 5, paraphyses and an ascus. Fig. 6, 1-septate spores. Fig. 7, algal cells. Fig. 1, natural size; fig. 2, enlarged about 10 diameters; figs. 3, 4, enlarged 400 diameters; figs. 5-7, enlarged 650 diameters. From Schneider.

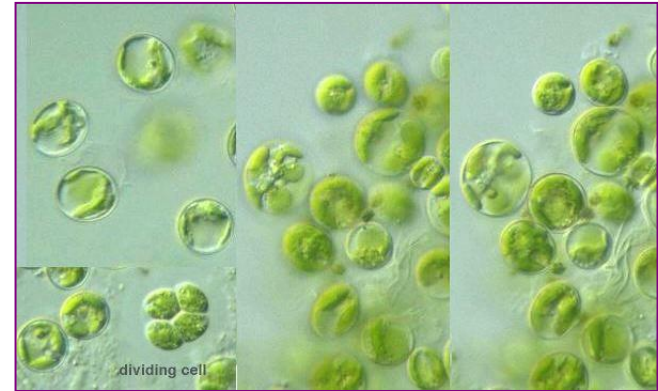
Nature of associations of algal and fungal partners

- Mycobiont usually takes up about 90% of the thallus and is usually an ascomycete (most are inoperculate discomycetes) or occasionally a basidiomycete (eg. *Omphalina*, *Multiclavula*).
- Photobiont may be a green alga, cyanobacterium or both. Both the algae and cyanobacteria fix carbon and the cyanobacteria fix nitrogen.

(What do we mean by lichen fix carbon and nitrogen?)

Nature of associations of algal and fungal partners

- 24 genera of green algae are lichenized; *Trebouxia* accounts for >75% of known lichens.
- About 10% of lichens have a cyanobacterium as the only or primary photobiont; most of these belong to *Nostoc*.



Mycobiont/Photobiont Interface

Table 21
Types of hypha–algal cell interaction in different genera of lichen algae

	Type of interaction ^a		
	Contact	Invagination	Penetration
Green algae			
<i>Trebouxia</i>	+	+	+
<i>Stichococcus</i>	—	+	+
<i>Myrmecia</i>	—	—	+
Blue-green algae			
<i>Gloeocapsa</i>	+	+	—
<i>Nostoc</i>	+	—	—
<i>Scytonema</i>	—	+	—
<i>Calothrix</i>	+	—	—
<i>Stigonema</i>	+	—	—

^a + present; — absent.

Mycobiont/Photobiont Interface

Intercellular
haustoria or
wall to wall
contact.

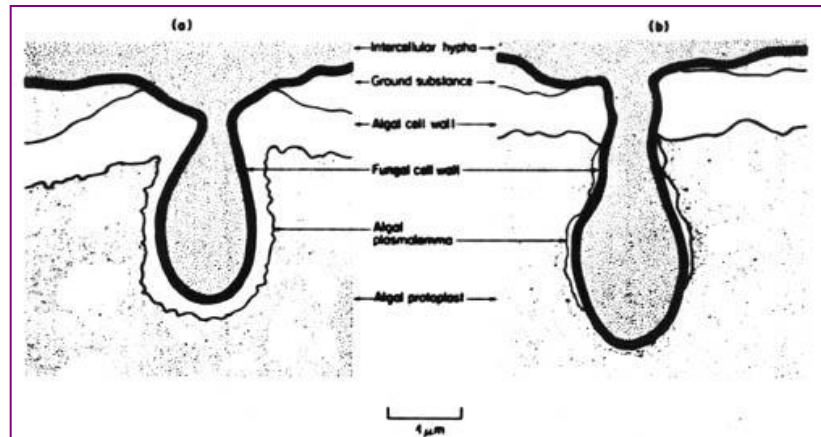


Figure 66 Diagram of mode of penetration of algal cells by hyphae within lichen thalli: (a) invagination but no rupture of host cell wall; (b) rupture of host cell wall and invagination of algal plasmalemma



Figure 1 Algal types with associated fungal hyphae. a, Cystococcus, each cell surrounded by haustoria. b, Trentepohlia, showing a branching chain of cells, surrounded by haustorial hyphae. c, Nostoc, showing the algal filaments and the intermingled fungal hyphae. d, Gloeocystis, showing the haustoria and the fungal hyphae surrounding the algal cells. e, enlarged 750 diameters; b, 325 diameters; c, 500 diameters; d, 650 diameters. From Schneider.

Advantages to the alga?

- Mechanical protection from injury & high light by being tightly enveloped by hyphae.
- Improved water relations and resistance to desiccation.
- Provides minerals.

Advantages to the fungus?

- Organic nutrients (carbon & nitrogen) provided by photobiont.
- Lichenized fungi have greater longevity.
- Most lichenized fungi are never found free-living in nature.

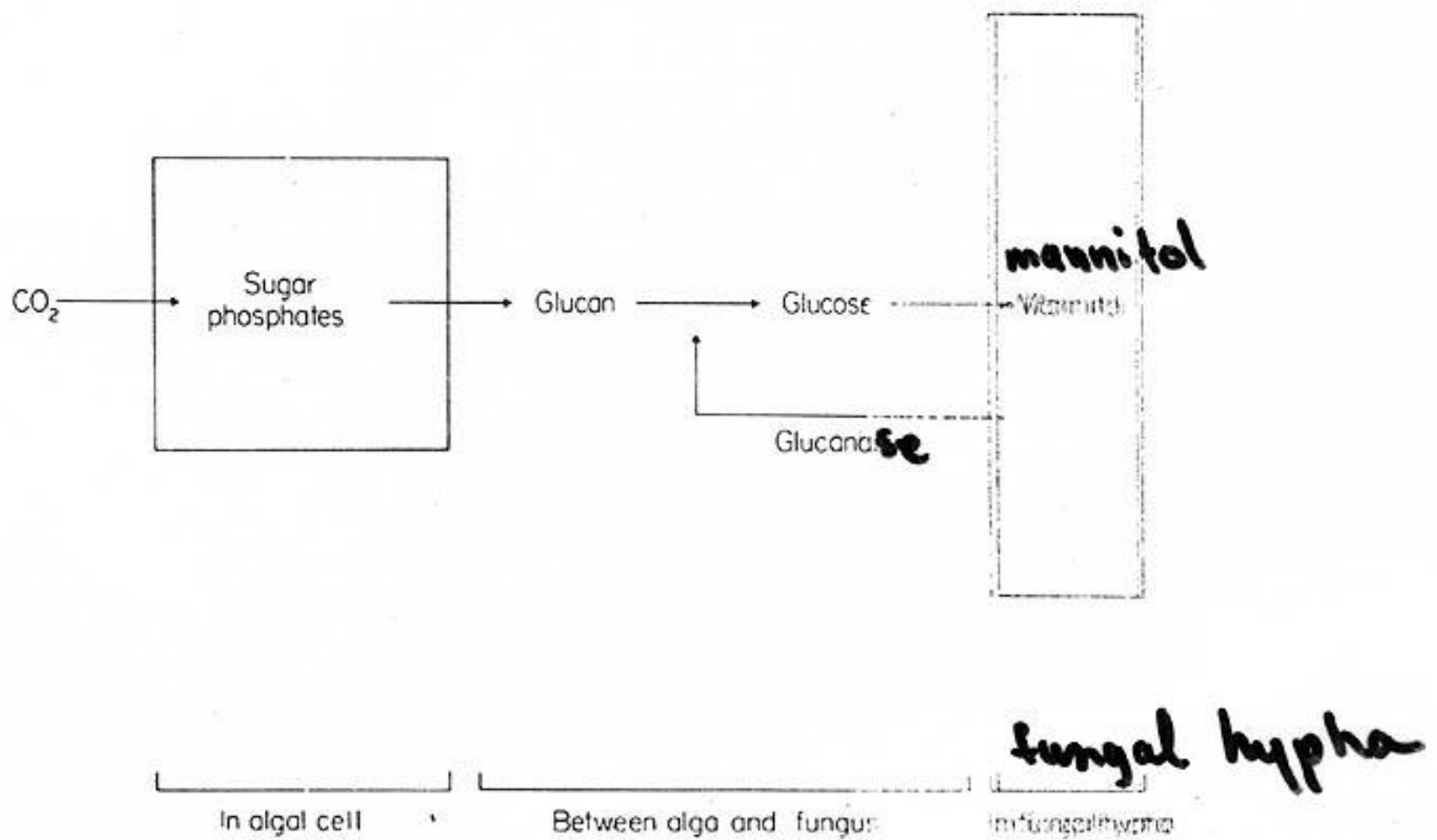


Figure 71 *Peltigera polydactyla*, possible mechanism of transfer of photosynthate from alga to fungus. After Hill, 1972

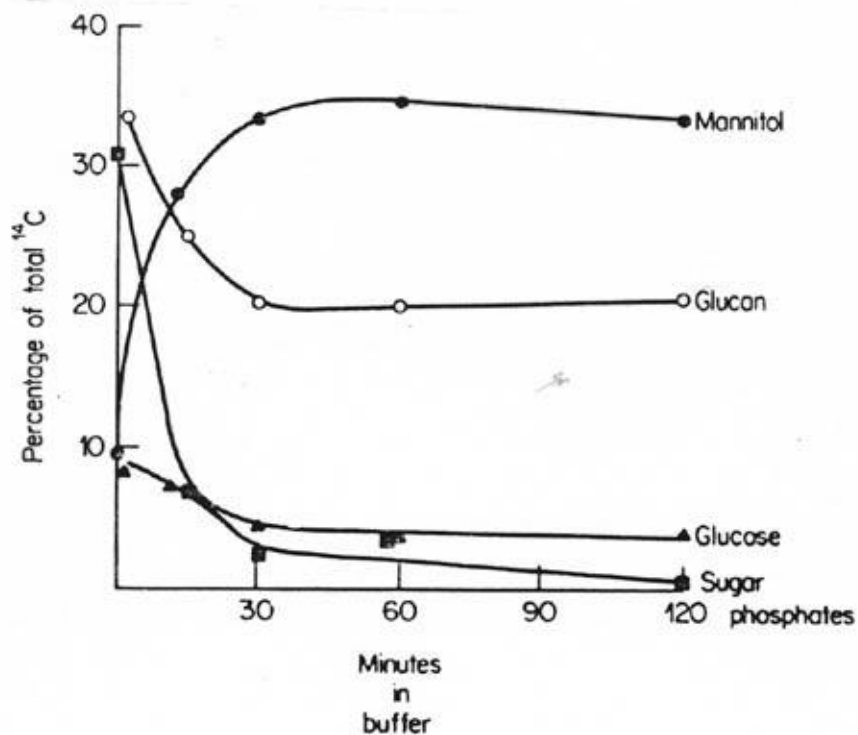


Table 24
Changes in levels of ^{14}C in fractions after pulse feeding with $^{14}\text{CO}_2$ (after Hill, 1972)

Fraction	Change in ^{14}C after pulse as percentage of total counts
Mannitol	+50
Glucose	-3
Sugar phosphates	-31
Glucan	-16
total -50	

Figure 70 *Peltigera polydactyla*, redistribution of ^{14}C in various fractions after pulse feeding with labelled CO_2 followed by incubation in buffer. Modified from Hill, 1972; by permission of *New Phytologist*

Some lichens have been taken apart and put back together again but environmental conditions must be just right for reassociation to occur.

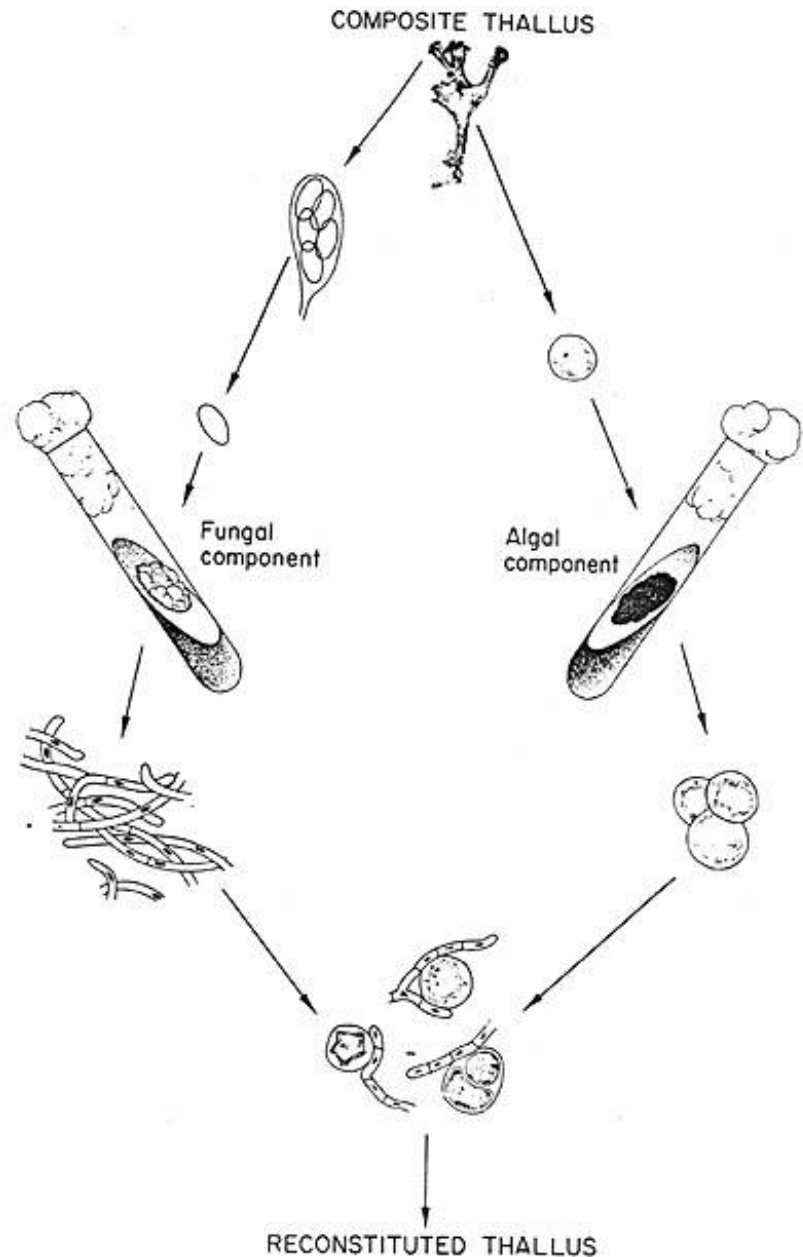


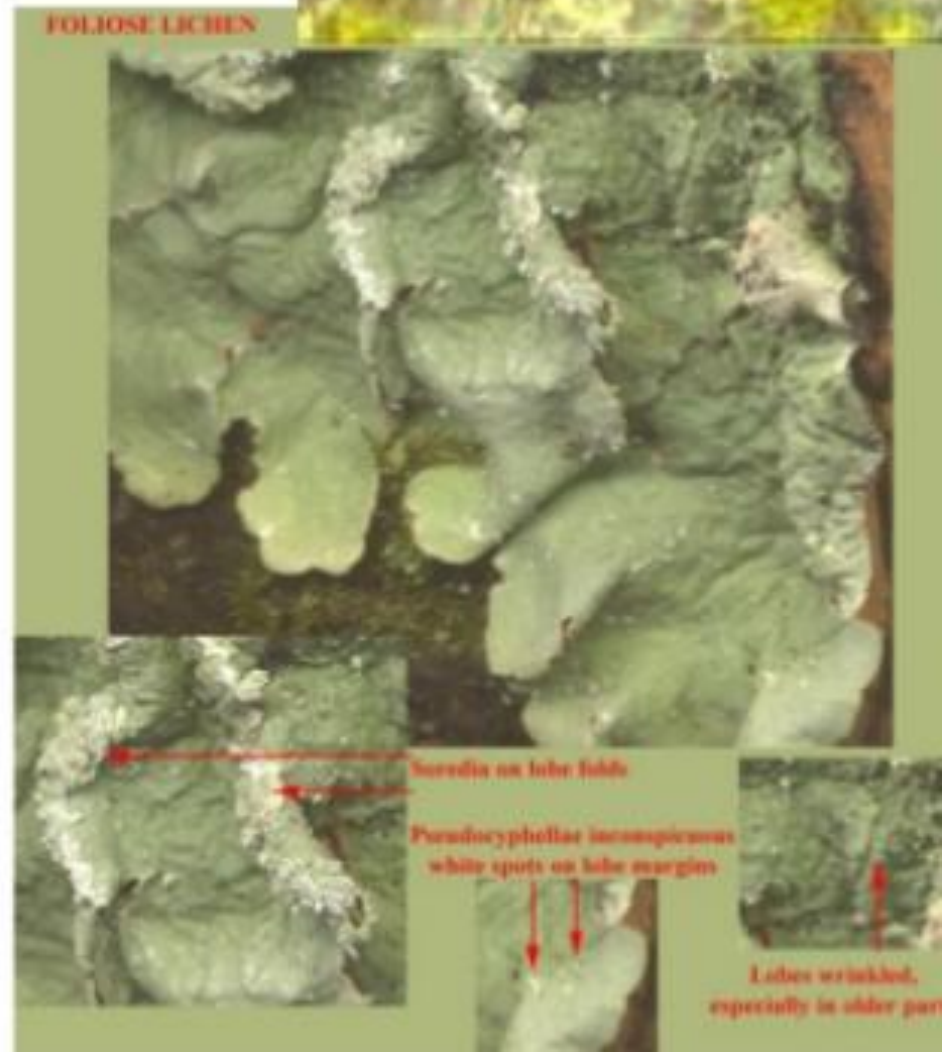
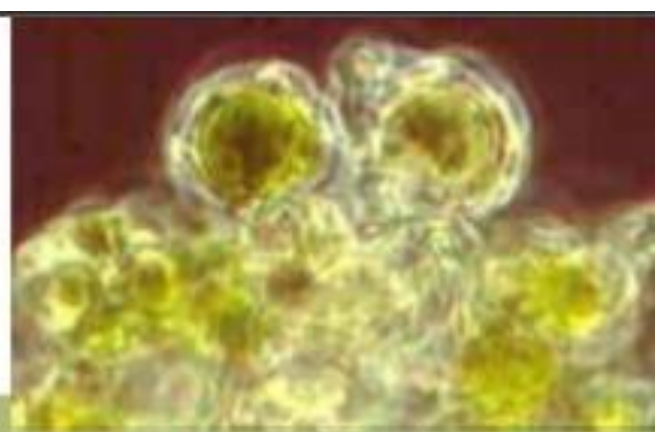
Fig. 5.1 Steps in the experimental reconstitution of *Cladonia grayi*. (Drawings by N. Halliday)

Reproduction

- Meiospores (ascospores & basidiospores).
- Conidia
- Vegetative propagules
 - **Cephalodia** - gall-like swellings containing cyanobacteria on or in thallus with algal photobiont; primary function is nitrogen fixation, but may also be a propagule.
 - **Isidia** - small, cortex-covered protuberances containing fungal and algal cells.
 - **Soredia** - A few algal cells surrounded by fungal hyphae formed in small, pustule-like breaks in cortex called soralia.

Asexual reproduction

- Specialized structures
- Soredia - algal cells enveloped by hyphae, no cortex, form powdery masses on surface of thallus, detach from thallus
- Isidia – column like structures with cortex

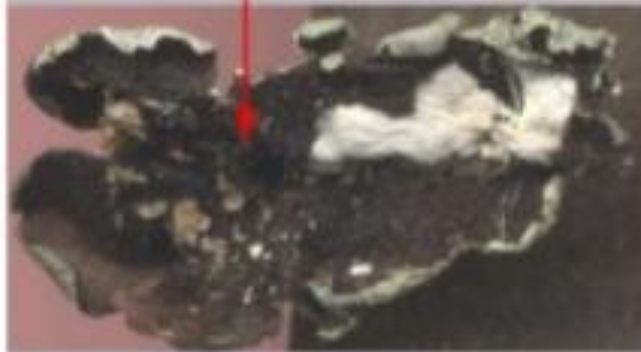


Isidia

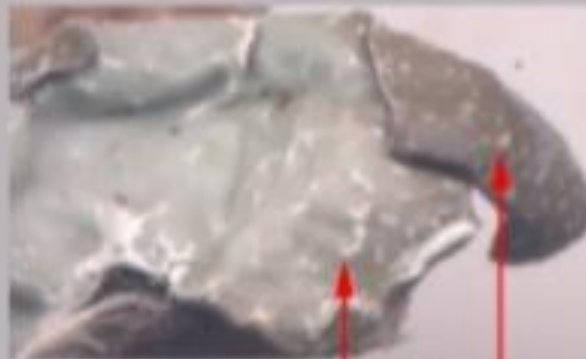
FOLIOSE LICHEN



Lower surface black



Isidia on lobe surface and margins



Pseudocyphellae conspicuous, especially on ridges



Economic importance

Economic importance of lichen:

- Lichens are the pioneers of rock vegetation
- Lichens initiates xerarch type of plant succession on rock
- Lichen acid cause weathering of rock into soil particles
- Some lichens are ecological indicators, they acts as indicators of pollution
- *Cladonia rangiferina*, which is luxuriously grows in polar region act as the food source for some animals such as reindeers
- *Lecanora* is consumed as food by human
- *Peltigera canina* and *Lobaria pulmonaria* are medicinal

Economic importance

Economic importance of lichen:

- *Prmelia* is used as a spice or condiment in some parts of India
- *Rocella* and *Lecanora* yield dye called orchil or orecin or Cudbear which are used for colouring woolen and silk fabrics
- Orecin is an excessively used chromosomal stain, it is used for the 'O' banding of chromosomes
- *Lobaria pulmonaria* is used in tanning, perfumery industry. It is also used as 'hope' in brewing industry.



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Mycorrhiza

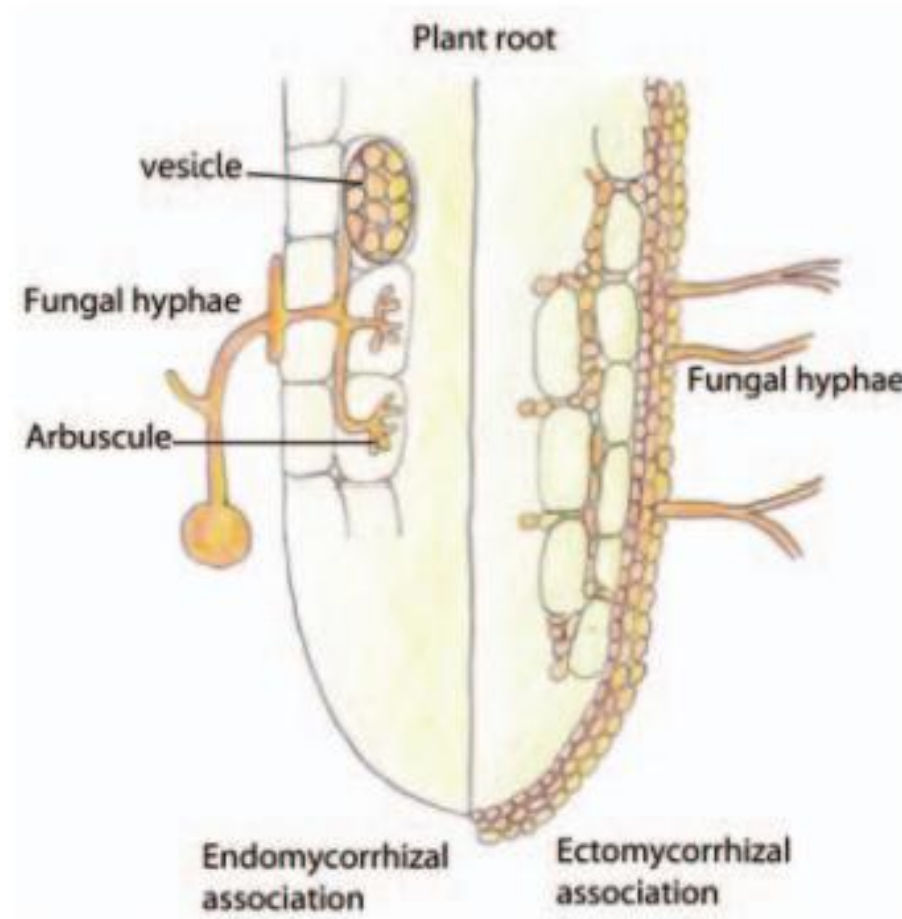
The Oldest Association Between Plant and Fungi

- The symbiotic association between plant and fungi (mycorrhizal association) is an amazing phenomenon observed in nature.
- The term 'mycorrhiza' comes from Greek – mycos meaning fungus and rhiza meaning roots.
- In nature, more than eighty percent of angiosperms, and almost all gymnosperms are known to have mycorrhizal associations.
- Mycorrhizal associations help the host plants to thrive in adverse soil conditions and drought situations by increasing the root surface and mineral uptake efficiency.
- The mycorrhizal association is one of nature's boons for sustainable agriculture.
- In today's changing environment, indiscriminate use of pesticides and chemicals pose a great threat to the existence of mycorrhizal species.

- There are mainly two types of mycorrhizal associations found in nature namely:

- **Endomycorrhizae or Arbuscular-mycorrhizae (AM),**

- In endomycorrhizal association of the vascular-rbuscular (VA) type, the fungi penetrate the cortical cells of roots and form clusters of finely divided hyphae which ultimately develops into arbuscules (small ellipsoidal structures).
- VA fungi forms a mutualistic association with around 80% of vascular plants. It belongs to the phylum Glomeromycota.
- eg., *Endogone*, *Rhizophagus*, etc.



Schematic representation of endo- and ectomycorrhizal association between plant and fungus.

➤ Ectomycorrhizae (EM)

- The ectomycorrhizal fungi invade a partial region of the host root without penetrating the cortical cells and form a thick mantle around the roots.
- Ectomycorrhizal associations are present in 3% of vascular plants and the fungi belong to the phylum Ascomycota and Basidiomycota.
- eg., *Laccaria bicolor*, *Amanita muscaria*, etc.

Ecto- vs Endo-mycorrhizae

2,000 species of plants -- mainly trees
→ 18 families

Gymnosperms:

ALL Pinaceae

Angiosperms:

ALL *Fagaceae* (beech),
Betulaceae (birch),
Salicaceae (willow),
Dipterocarpoideae (lauan)

MOST *Myrtaceae* (eucalypt)

MANY legumes

SOME *Aceraceae*

Euphorbiaceae,

Rosaceae

Tiliaceae

Ulmaceae

7 other families

>300,000 species of plants -- both
herbaceous and woody
→ 380 families

NOT endomycorrhizal → many

ALL *Brassicaceae*

Commelinaceae (*Tradescantia*),

Juncaceae (rush)

Cyperaceae (sedge)

Proteaceae,

SOME *Amaranthaceae* (*Celosia*),

Caryophyllaceae (carnations),

Chenopodiaceae (spinach),

Polygonaceae (buckwheat),

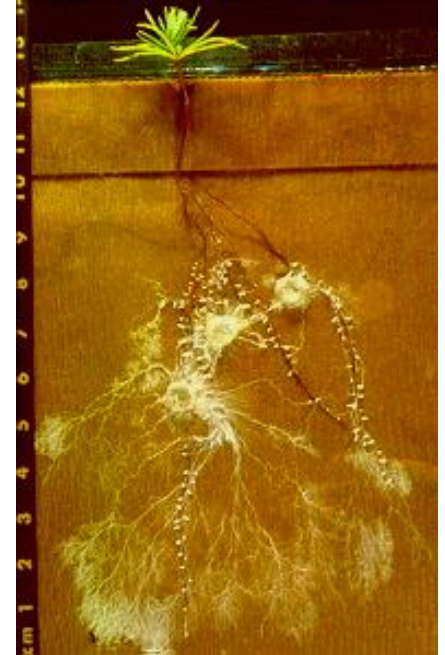
members of 3 other families

MOST ectomycorrhizal spp.

Overall, >95% plant species are thought to have mycorrhizal associates

General roles of mycorrhizae

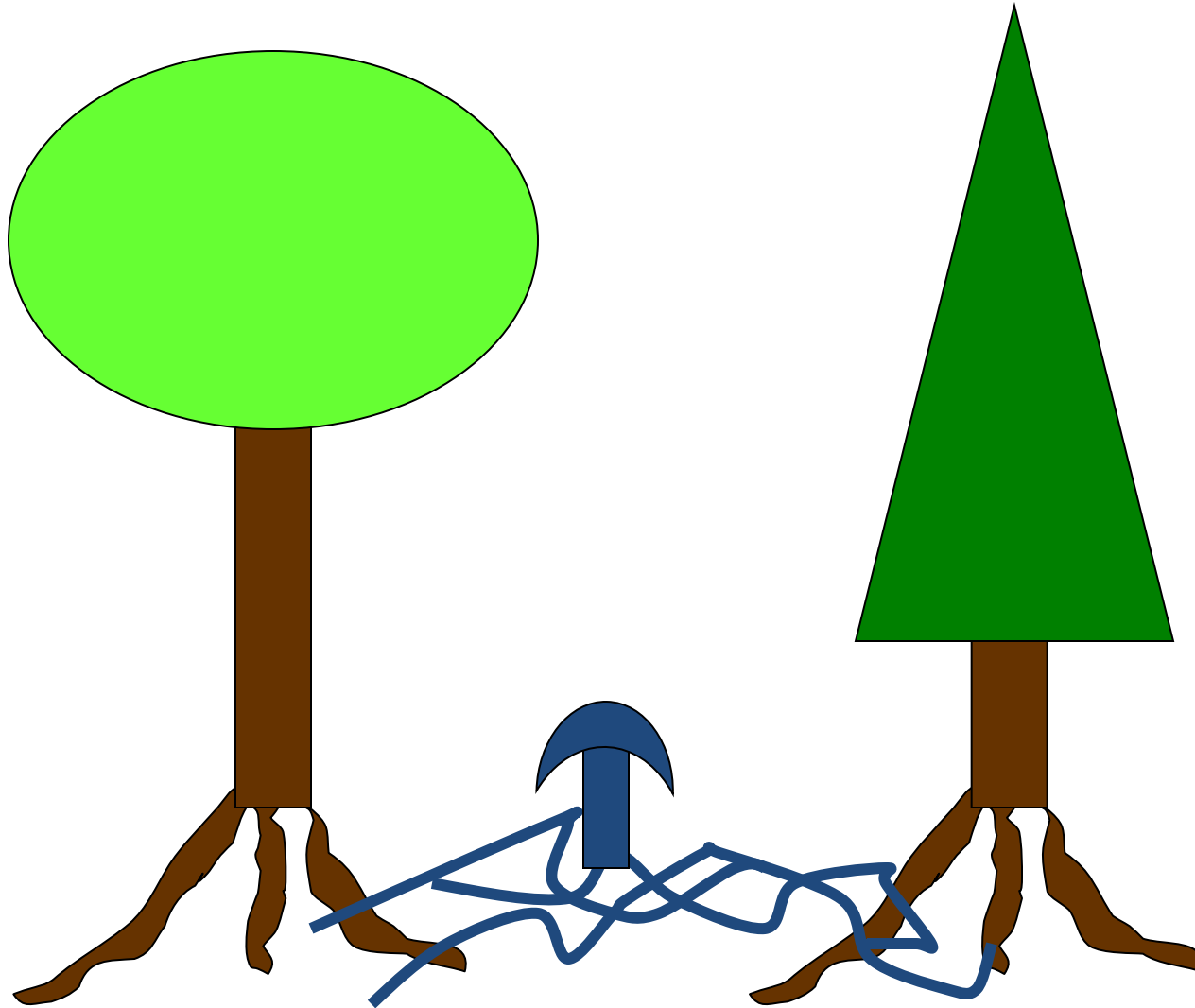
- Mycorrhizal plant can exploit several times the volume of soil available to a non-mycorrhizal plant
 - Environment to plant
 - Plant to/from fungus
 - Between plants – ecological integration
- Pathogen relations
 - Physical protection
 - Antibiotics
 - Increased plant vigour



Mycorrhizae may also

- induce antibiotic production by the plant
- alter the quantity and quality of root exudates
→ affects rhizosphere microflora
- improve host vigor → for improved resistance

Mycorrhizae as ecosystem integrators



Major types of mycorrhizae

- Ectomycorrhizae
- Arbuscular (endomycorrhizae)
- Ericoid
- Orchidoid
- Arbutoid
- Monotropoid

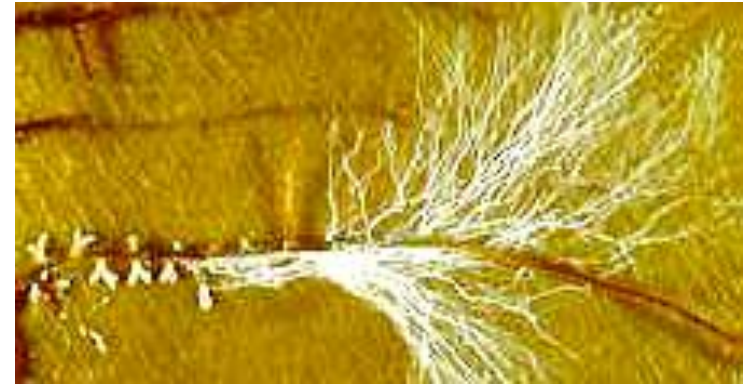
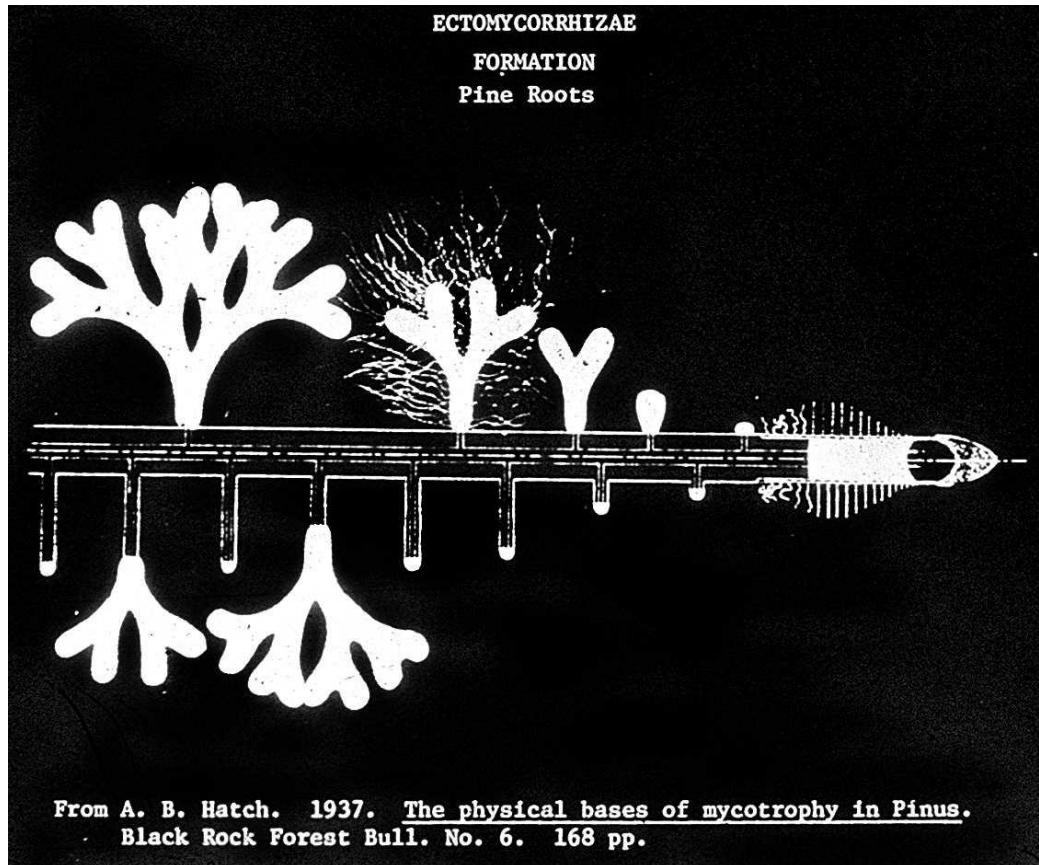
Ectomycorrhizae

- Only on actively growing (feeder) roots
- Persistent – months to years
- Fungal mantle and Hartig net
- Typically, fungal dikaryomycete symbionts do not produce cellulase
- Basidiomycetes
 - *Amanita*, *Russula*, *Suillus*, *Pisolithus*
- Ascomycetes
 - *Tuber melanosporium*





Root colonization by ectomycorrhizae



Amanita muscaria
on *Pinus strobus*

Heterorhizy

plant growth substances
produced/induced by fungus

promote/retain juvenile roots
reduced root hairs
prevent wood growth



Pisolithus tinctorius

- has been shown to establish mycorrhizas with ~ 50 different tree species

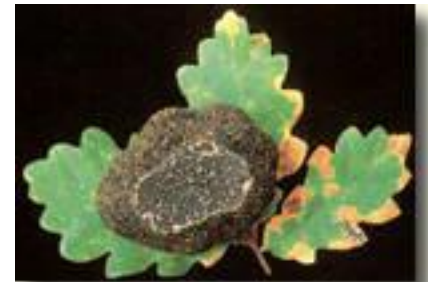


DJ Lodge



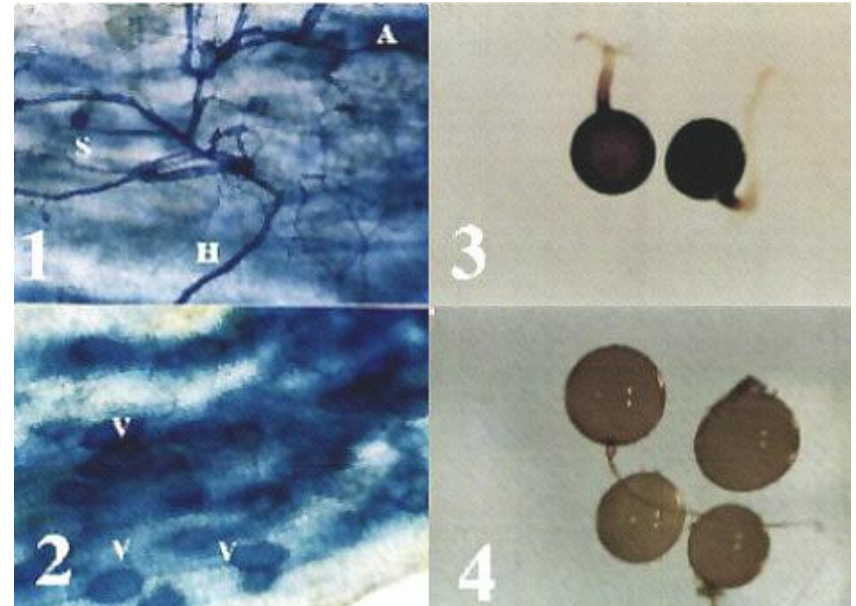
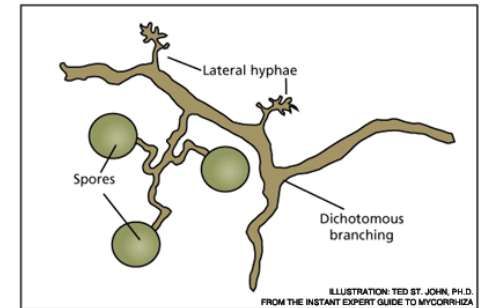
Ascomycete ectomycorrhiza

- Ascomycetes – *Tuber melanosporum*
\$2000/kg retail fresh
- Modified apothecium → gleba
- Mycorrhizal on oak, 125g/tree/year, full production in 10yr
- Cultivation, 1000 trees/hectare, 3m apart
- Crowded growth leads to faster fruiting

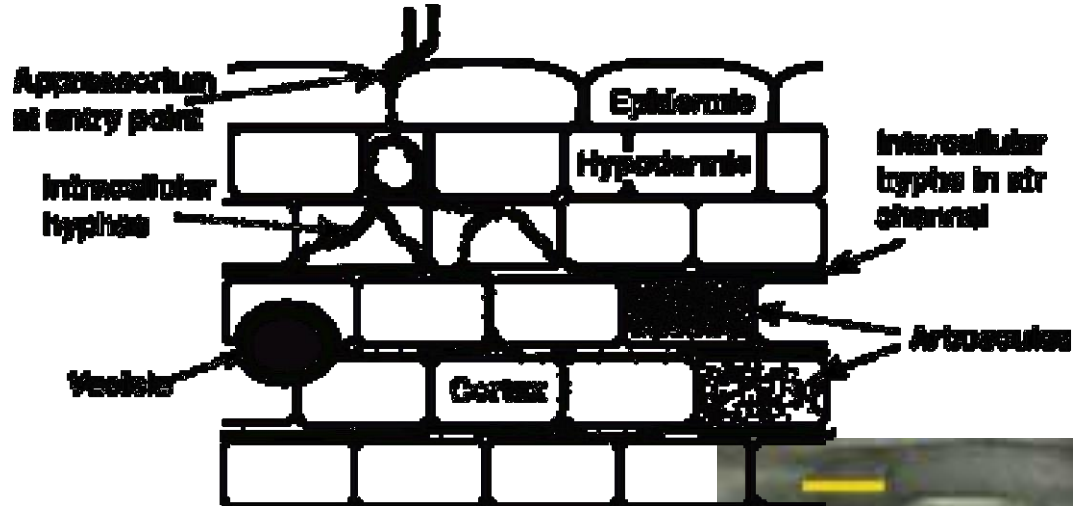


Arbuscular mycorrhizae

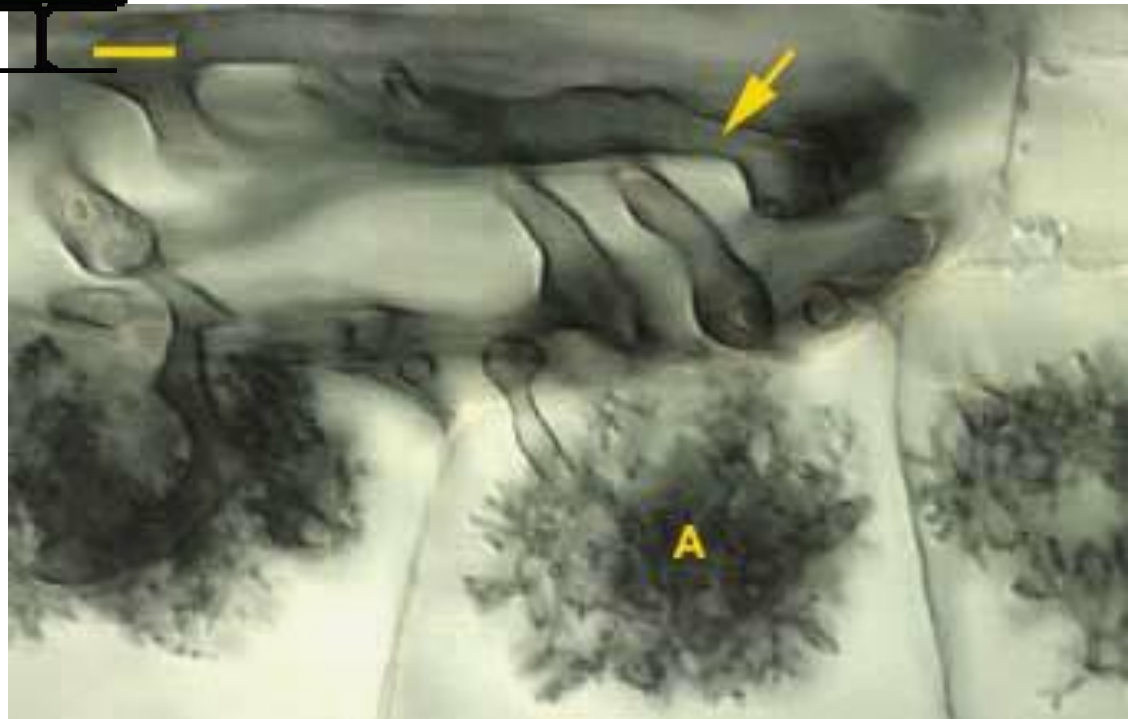
- Common especially on herbaceous plants; some trees *e.g.* sycamore
- Formerly Zygomycota/Glomales
 - now Glomeromycota
- Large sorocarps and spores produced adjacent to roots, but subterranean
- Obligate biotrophs, each interaction temporally limited → days to weeks
- Penetrates plant roots /cells



AM root colonization pattern

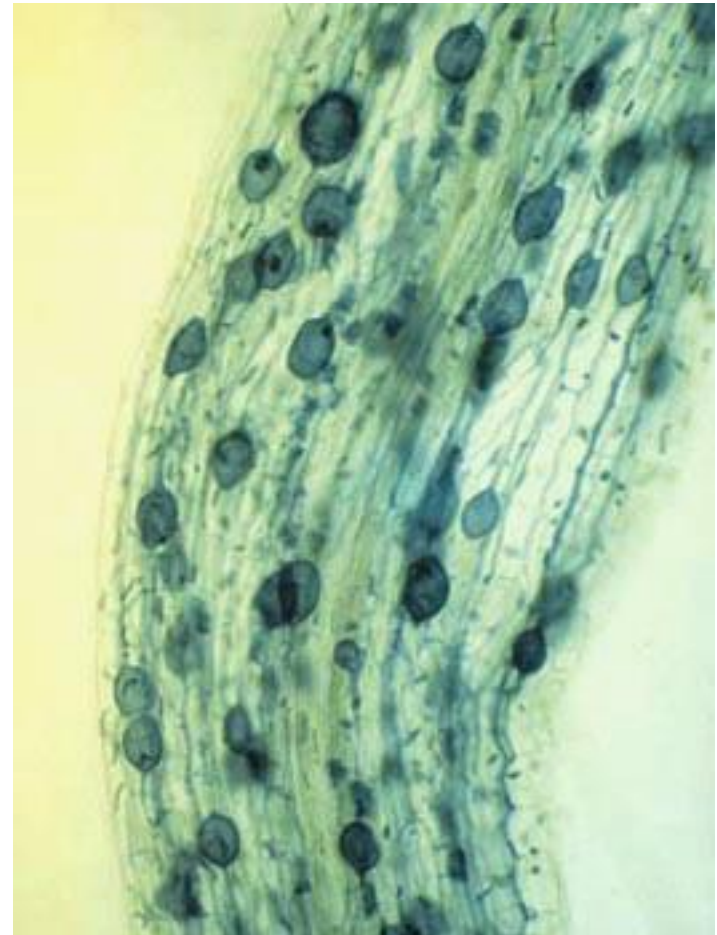


Cyclical formation of arbuscules followed by degradation
*may form vesicles



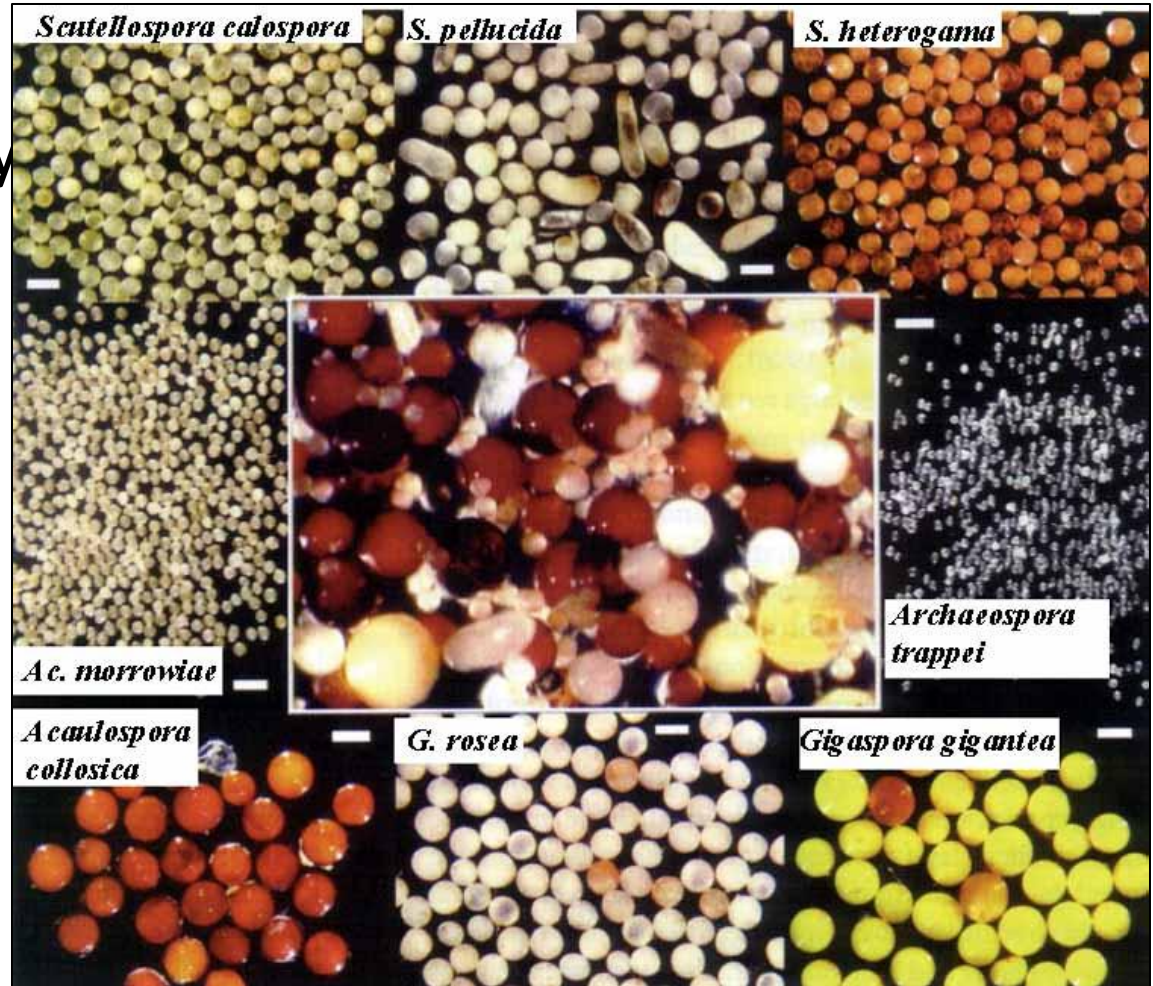
Formerly called Vesicular Arbuscular mycorrhizae

- Not all endo-mycorrhizae form vesicles
- May be final stage in limited term symbiosis
- May be characteristic of specific plant:fungus interactions

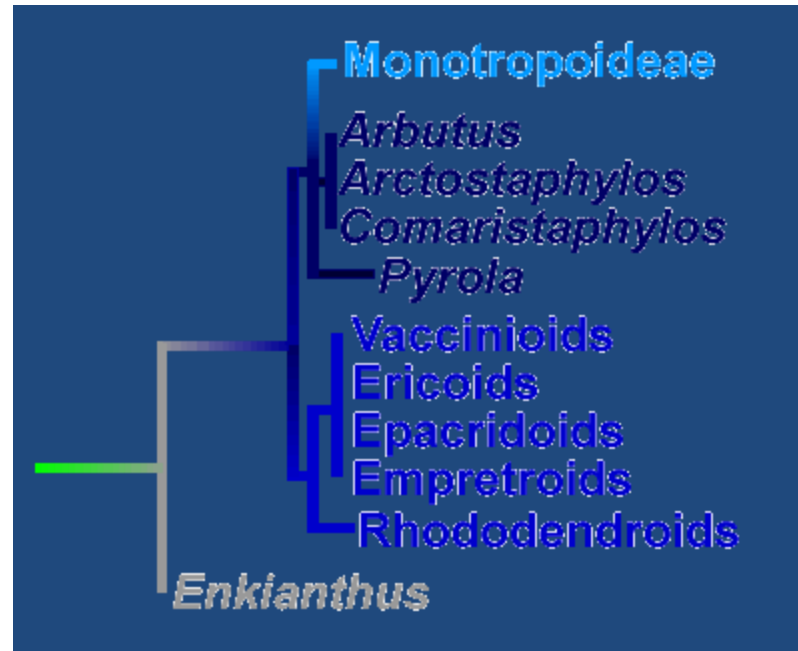


(Vesicular) arbuscular mycorrhizae

- Spore transport may be facilitated by burrowing animals
- Diversity is much larger than realized, until recently



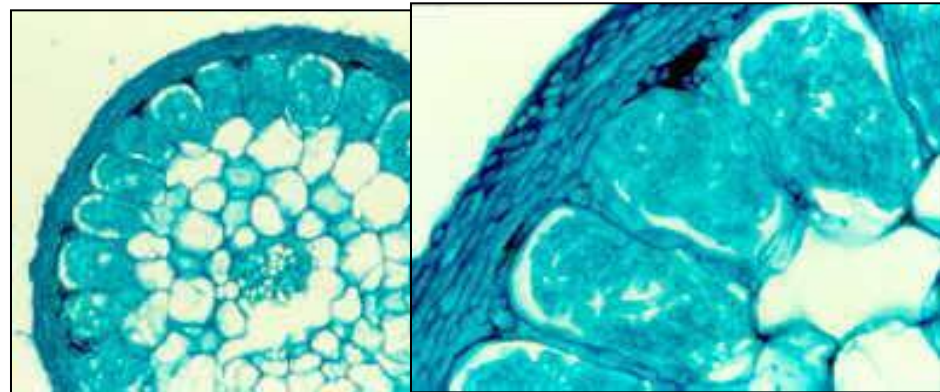
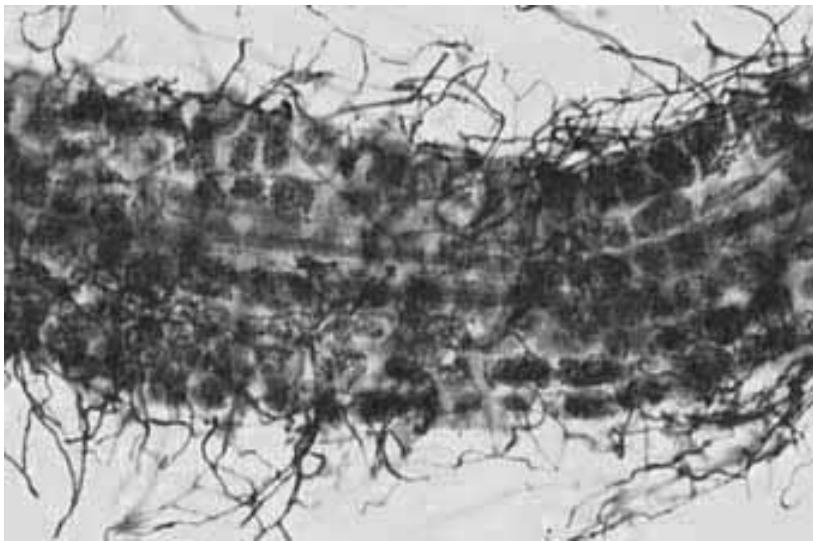
Other mycorrhizae groups



Bidartondo and Bruns 2001

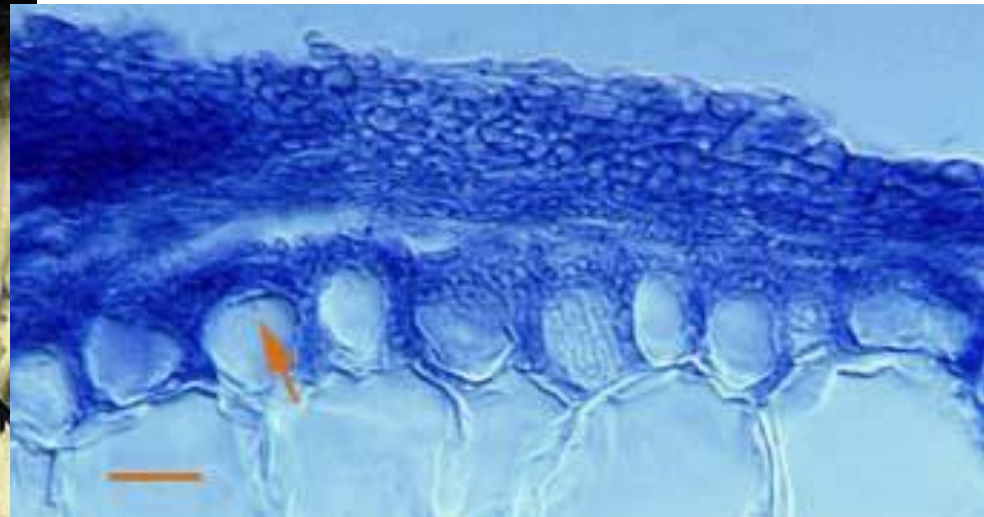
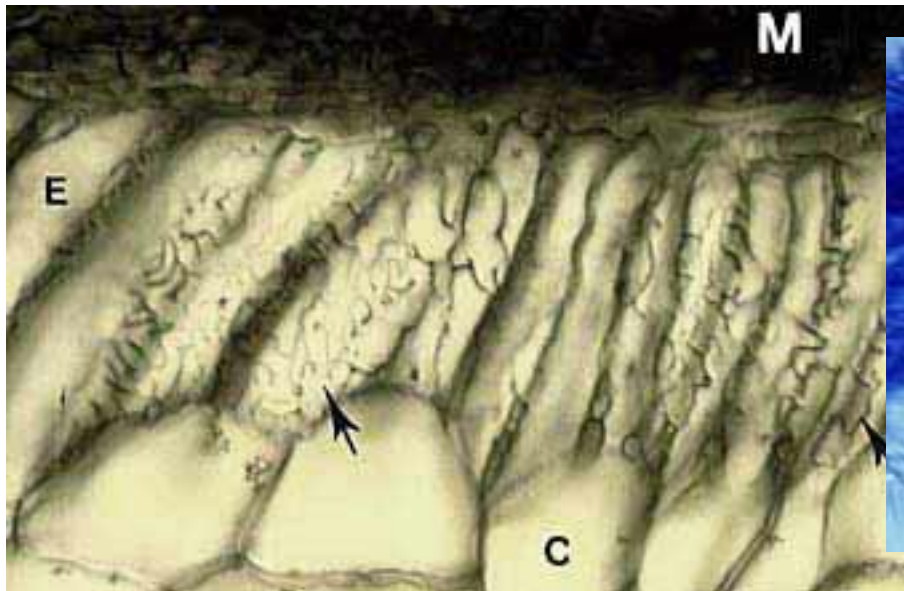
Ericoid mycorrhizae

- Important for nitrogen acquisition in boggy soil → includes invertebrate predation
- Colonized by some ascomycetes, e.g. *Hymenoscyphus ericae* (also forms mycorrhizae with liverworts)
- loose net over the growing (distinctive) hair roots
- fungus penetrates cortical cells → fills with densely coiled hyphae (not arbuscules)



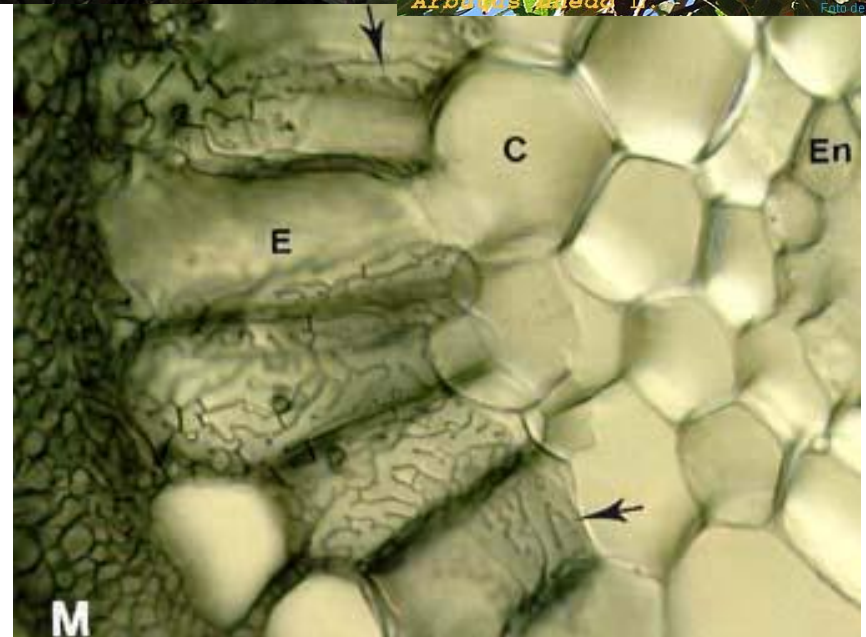
Ericoid mycorrhizae

- Hyphae penetrate roots, but **never** enter the cells
- Hartig net
- Plant identification helps understanding mycorrhizal relationship



Arbutoid mycorrhizae

- develop on short primary roots of *Arbutus* and *Pyrola*
 - mantle of fungal tissue
 - Hartig net
- differential characteristic: fungi penetrate the walls of root epidermal cells, forming branching hyphal complexes **in** the cell
- fungi that form arbutoid mycorrhizae:
 - ascomycetes and basidiomycetes that form ectomycorrhizae on other species (such as conifers)



Orchid mycorrhizae

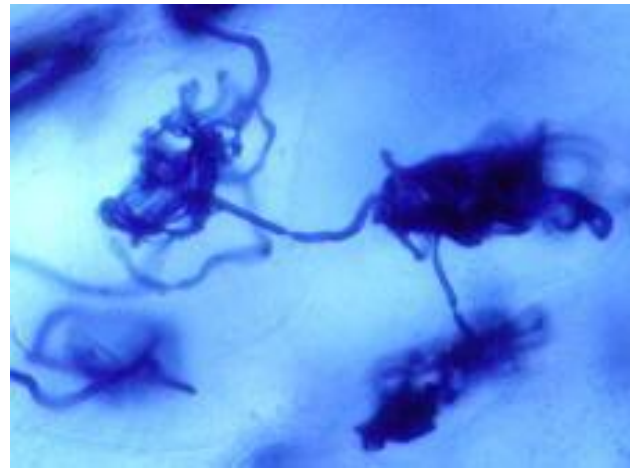
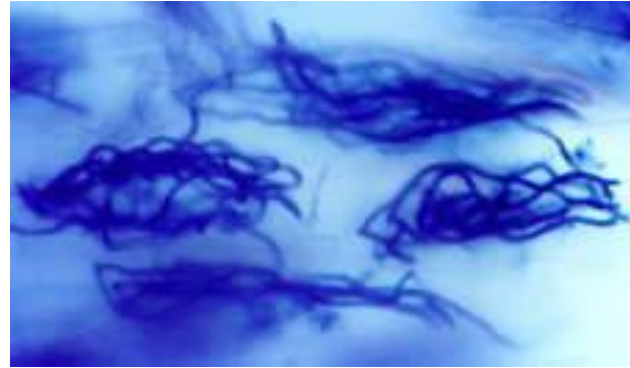
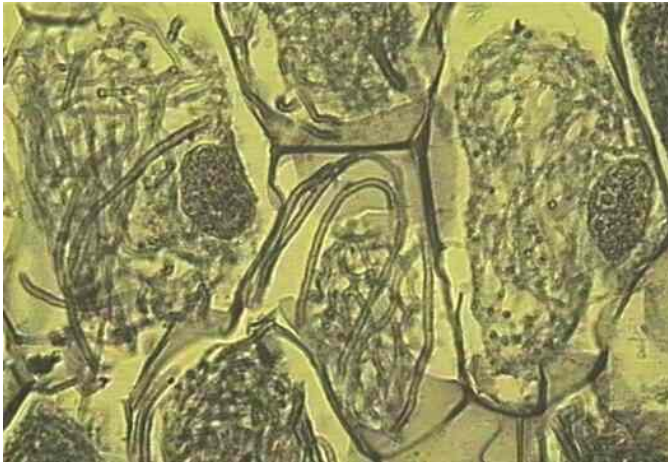
- Seedling orchid is entirely dependent on mycorrhiza for nutrition months ... years
- Achlorophyllous orchids
 - highly fungus specific
 - can parasitize ectomycorrhizal fungi (CHO from surrounding trees)
- Fungal partners
 - *Rhizoctonia* spp; some *Armillaria*
 - root pathogens, including some pathogenic isolates
- Both plant and fungus are live, but fungus degrades



Corallorhiza maculata



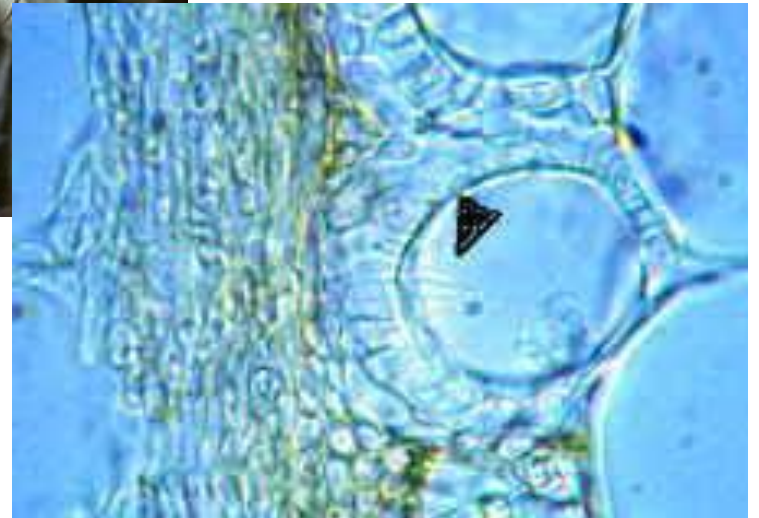
Orchidoid mycorrhizae – a balancing act



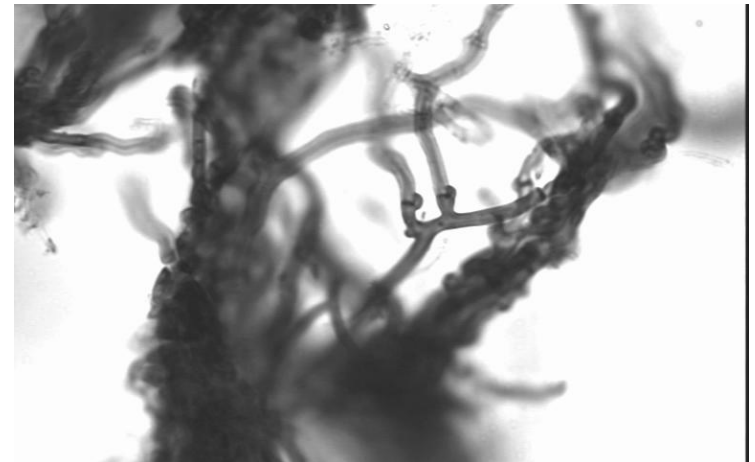
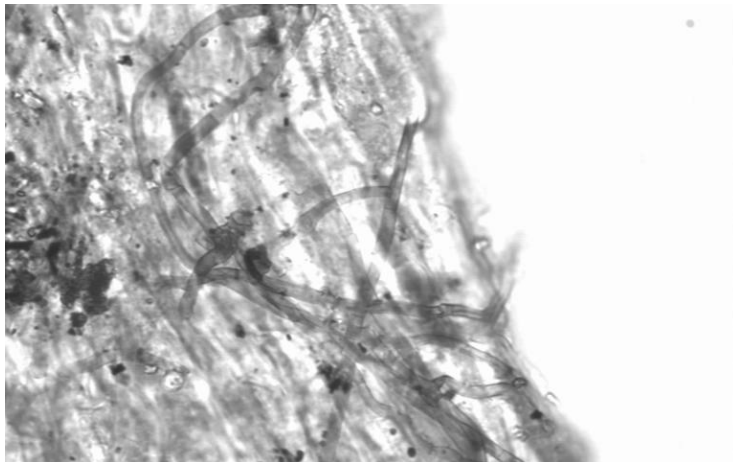
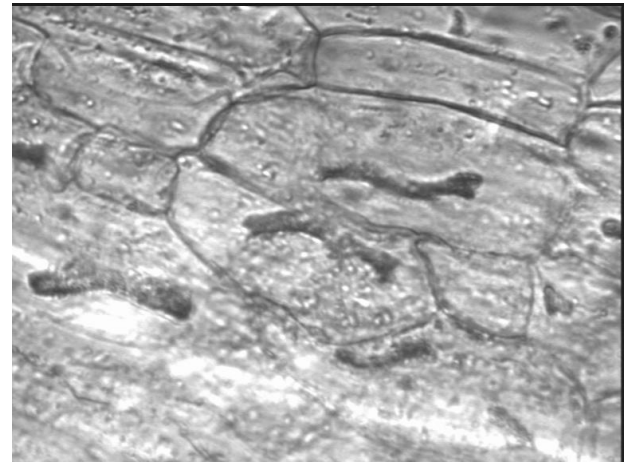
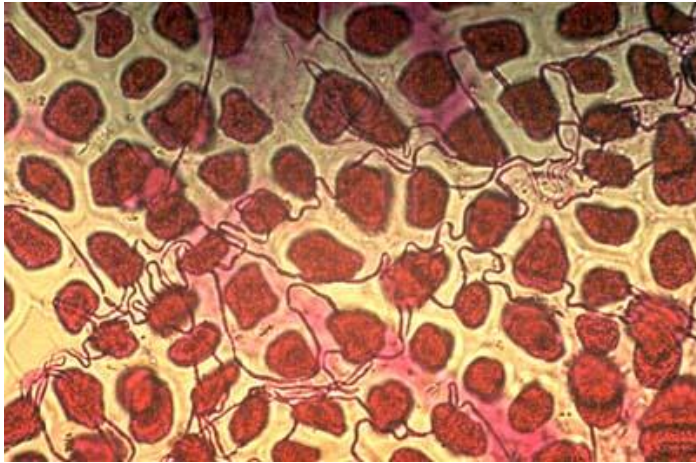
Monotropa depends on mycorrhizae



Arrowhead: penetration peg



Endophytic fungi



Perennial ryegrass

- Adapted to a wide range of soils, including heavy clay and poorly drained soils, but prefers well-drained soils of medium to high fertility. It tolerates soil pH ranging from 4.5 to 8.4
- Short-lived, cool-season perennial under western Canadian conditions
- Readily crosses with fescue spp, meadow and tall fescue



The fescue mystery

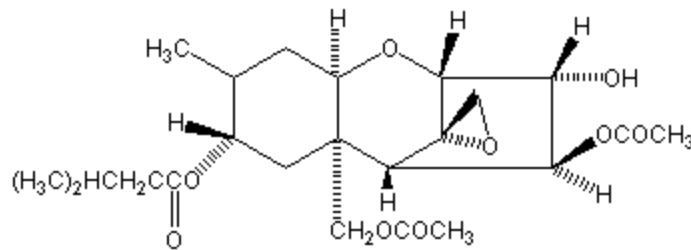
- Some fescue has relatively low palatability to livestock
- performance of animals grazing it was erratic and often disappointingly low
- cattle grazing fescue occasionally developed lameness and sometimes lost portions of their feet or tails during fall and winter
- mares grazing tall fescue pastures often aborted, produced stillborn foals, had thickened or retained placentas, or produced an inadequate quantity of milk

Acremonium coenophialum

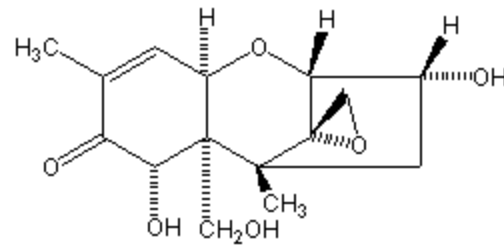
- **does not affect either the growth or appearance of the grass**
- **requires a laboratory analysis to detect its presence**
- **seed transmitted and apparently not transmitted in any other way**

Vomitoxin: deoxynivalenol (DON)

- mycotoxin produced by several species of *Fusarium*
- scab or head blight in barley, wheat, oats, and rye



Deoxynivalenol



T2 toxin