



the soil
microbiome



Sandra
Tuszynska
(PhD)

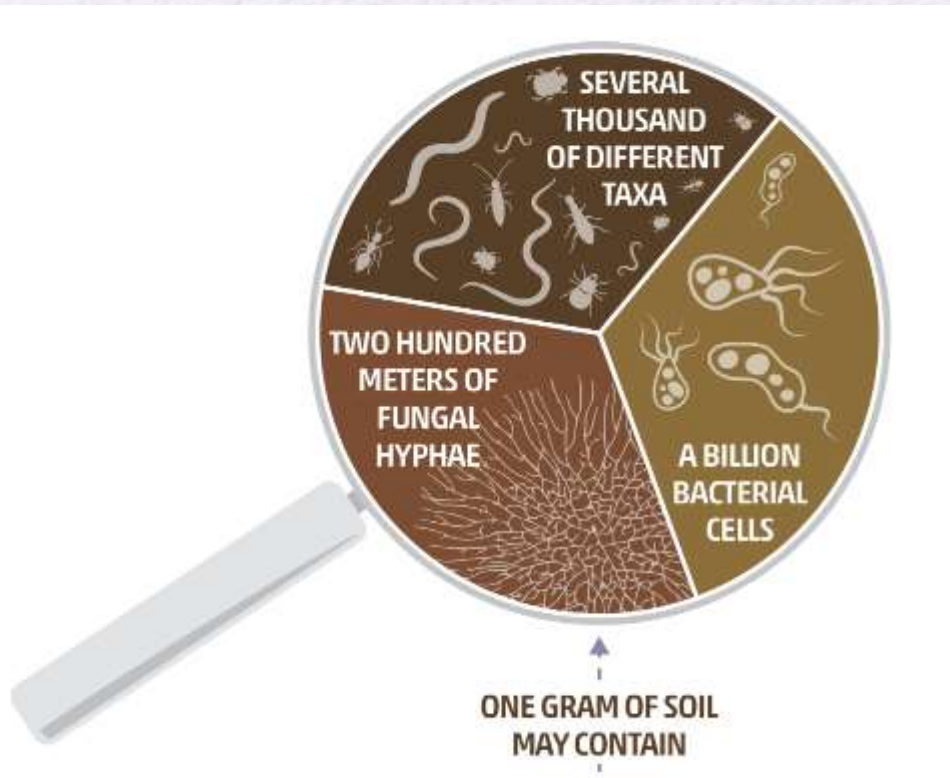


Dr. Elaine Ingham – Soil Food Web School



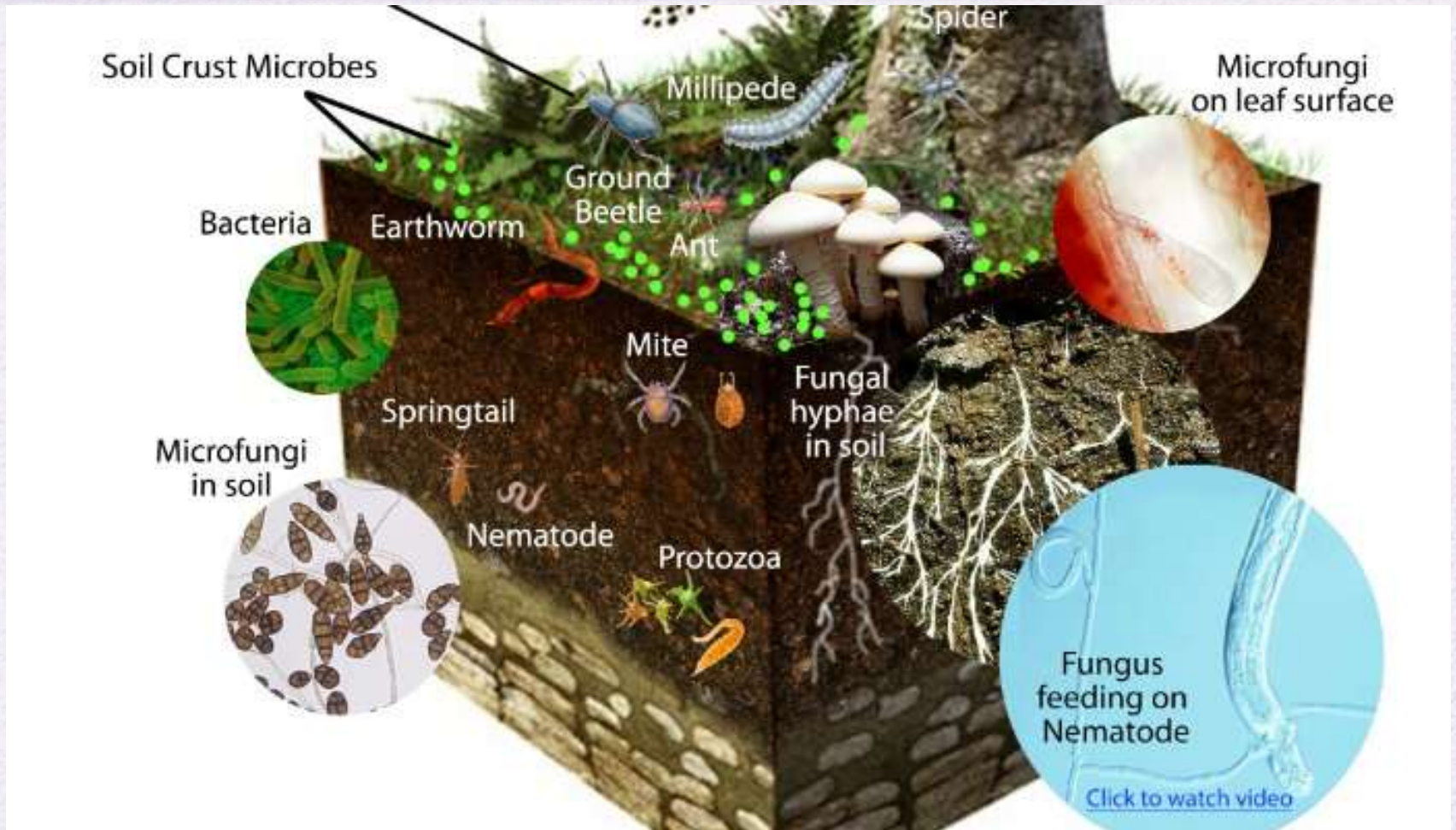
what is soil?

- Plants + associated microbes utilising sand, silt, clay and OM, solubilising and cycling nutrients



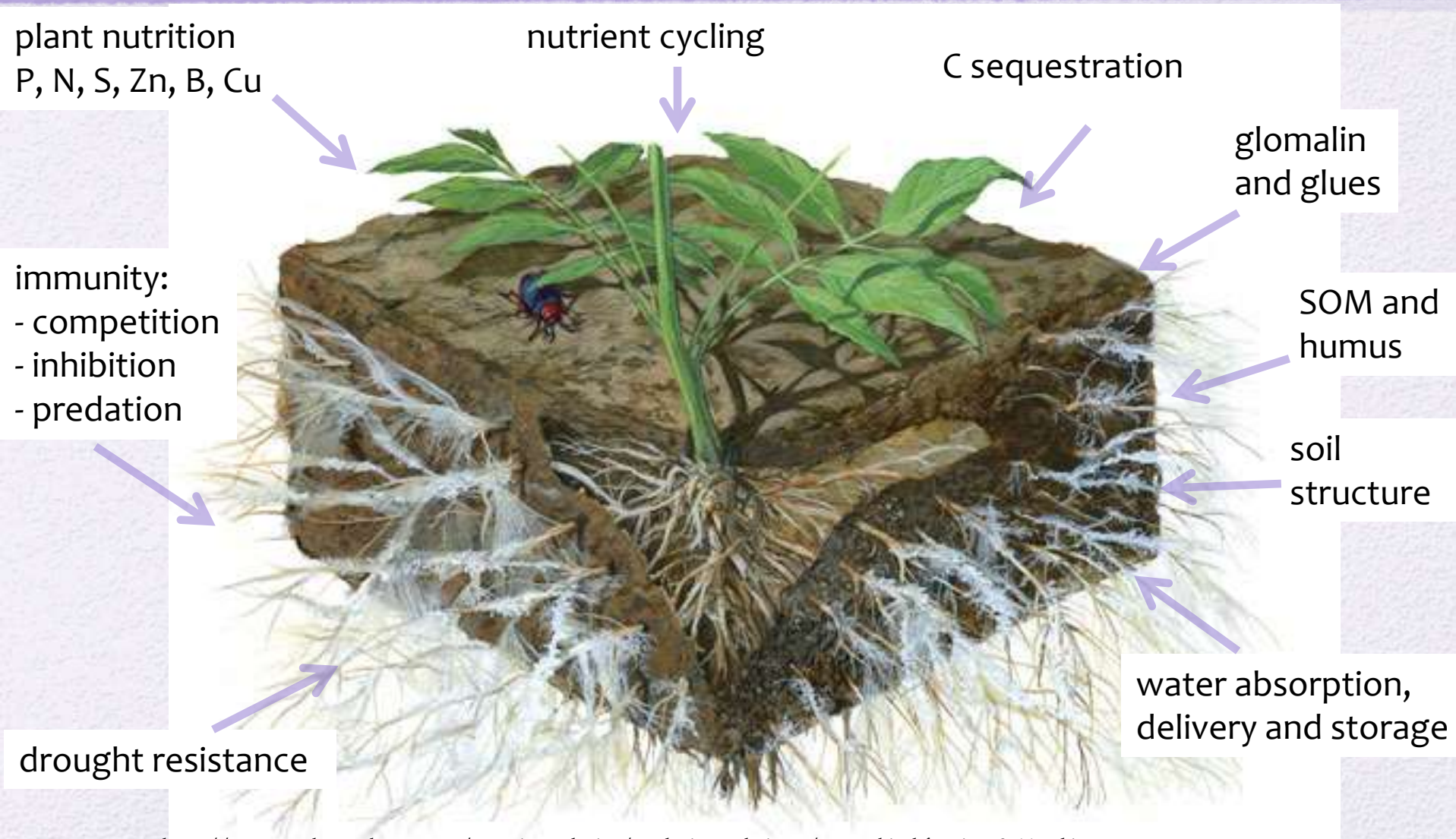
FAO, ITPS, GSBI, SCBD and EC. 2020. *State of knowledge of soil biodiversity - Status, challenges and potentialities, Report 2020*. Rome, FAO.
<https://doi.org/10.4060/cb1928en>

it's a living thing

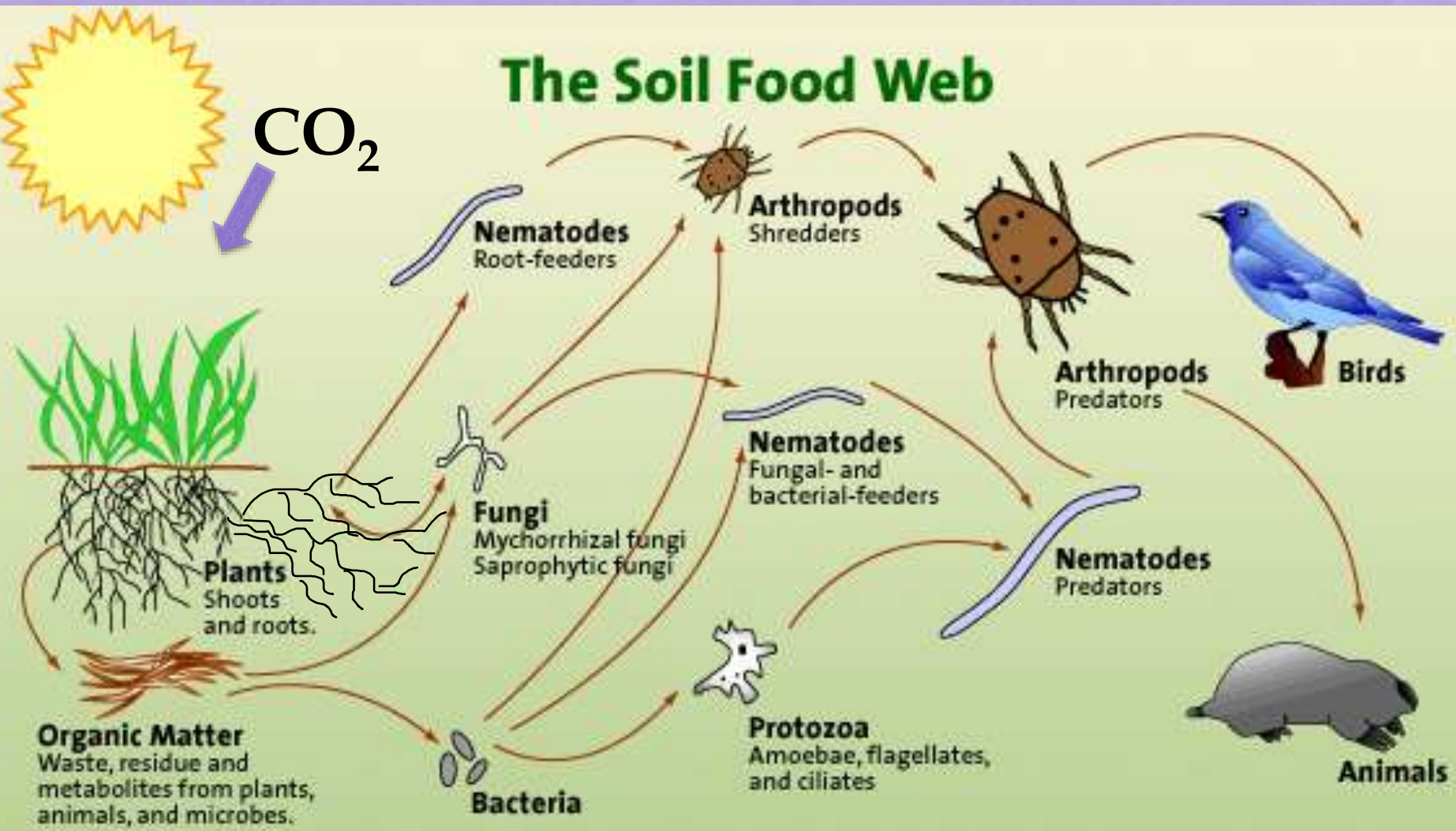


don't treat it like dirt!

plant services



The Soil Food Web



First trophic level:
Photosynthesizers

Second trophic level:
Decomposing Mutualists
Pathogens, Parasites
Root-feeders

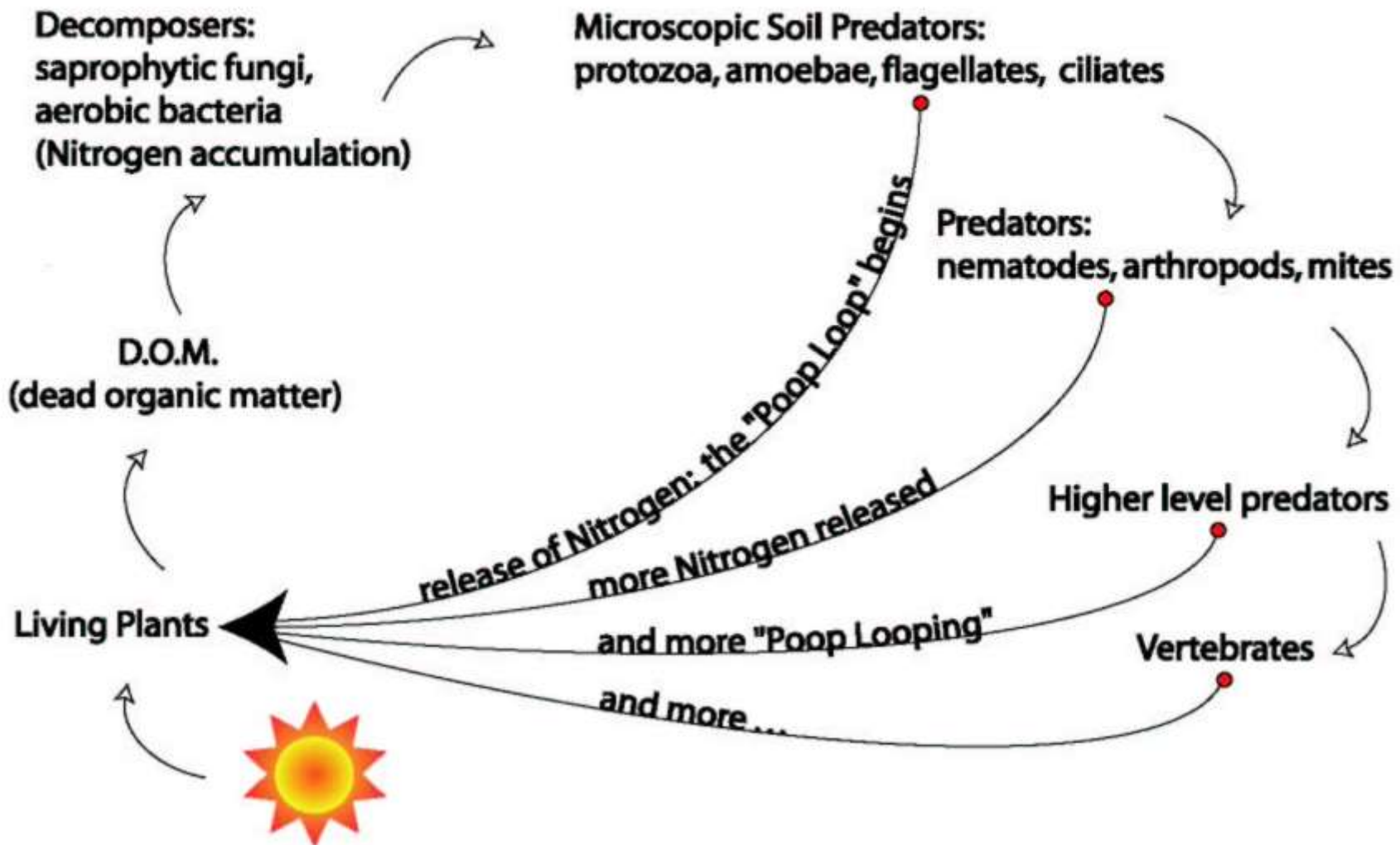
Third trophic level:
Shredders
Predators
Grazers

Fourth trophic level:
Higher level predators

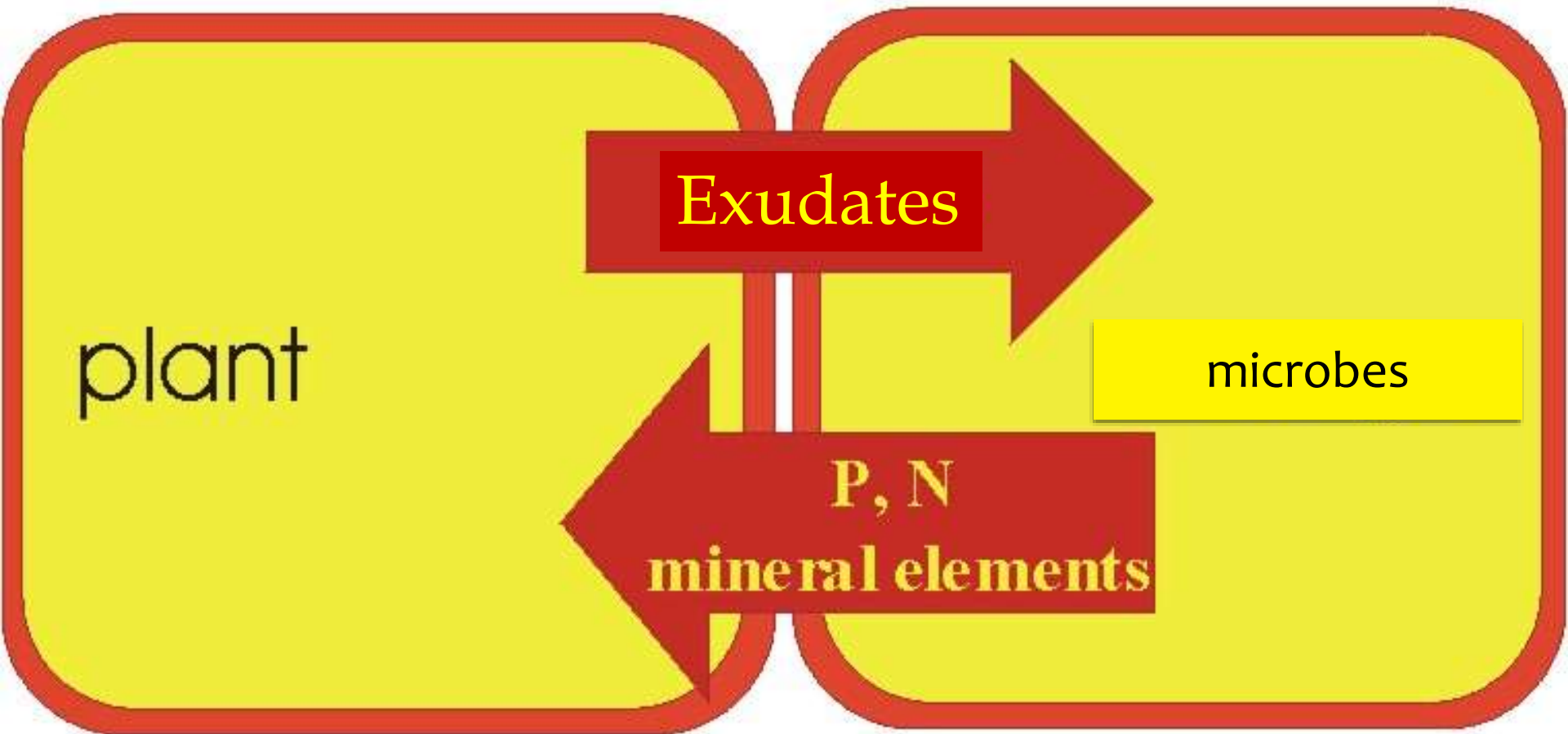
Fifth & higher trophic level:
Higher level predators

THE POOP LOOP

Based on information from Dr. Elaine Ingham and Soil Foodweb, Inc.
by Alane O'Rielly Weber, Botanical Art
(c) 2004

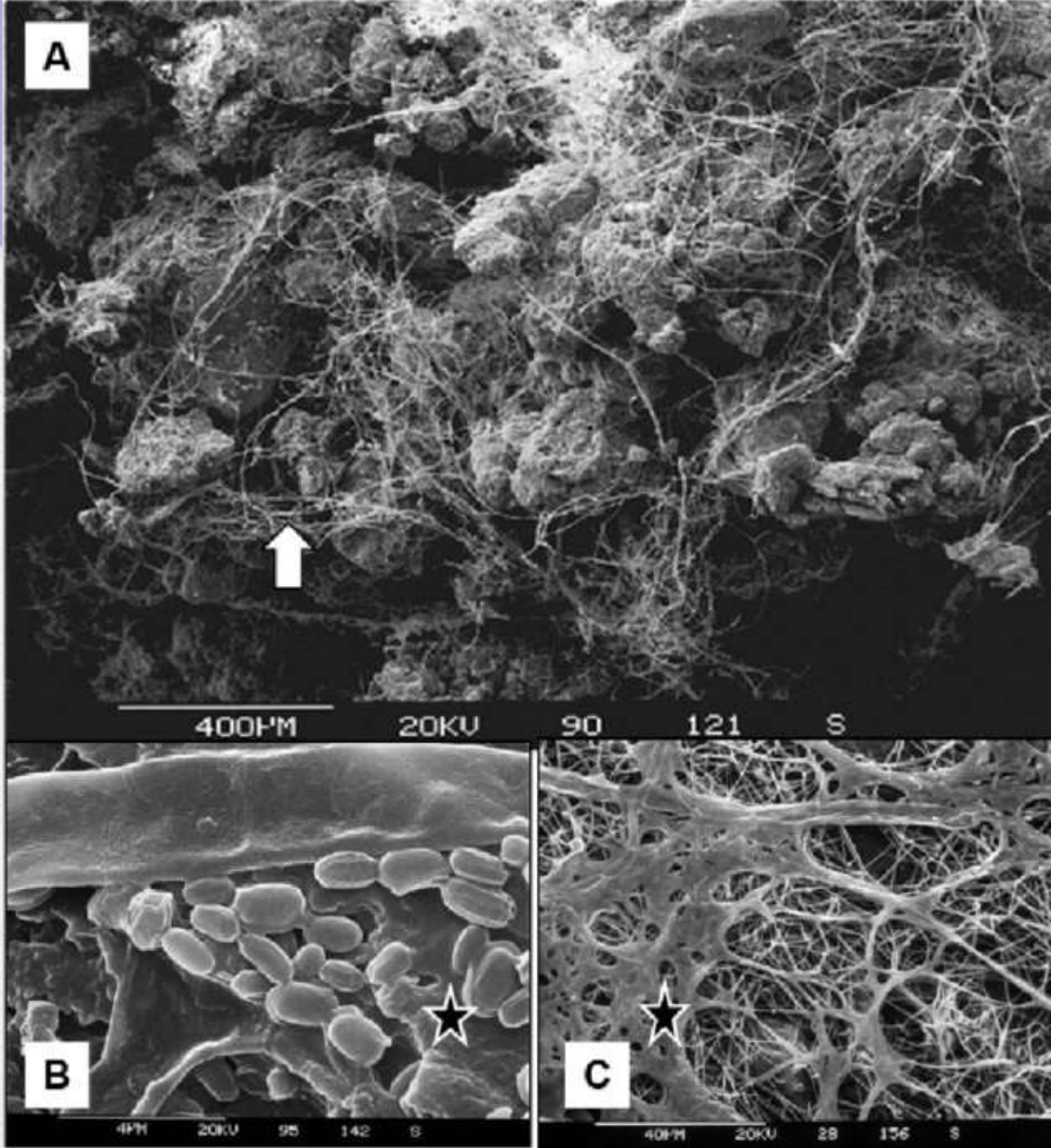


nutrient exchange



rhizosheath





- (A) network of fungal hyphae holding soil particles to crop residues
- (B) bacterial and fungal glues bind soil particles into stable aggregates
- (C) stable aggregates

(Gupta VVSR, CSIRO)

meet the team



bacteria

extract mineral
nutrients from rock

mineralize and transform organic
and inorganic compounds

fix N_2 into NH_4^+

nitrify NH_4^+ into NO_3^-

Credit: Steve Gschmeissner

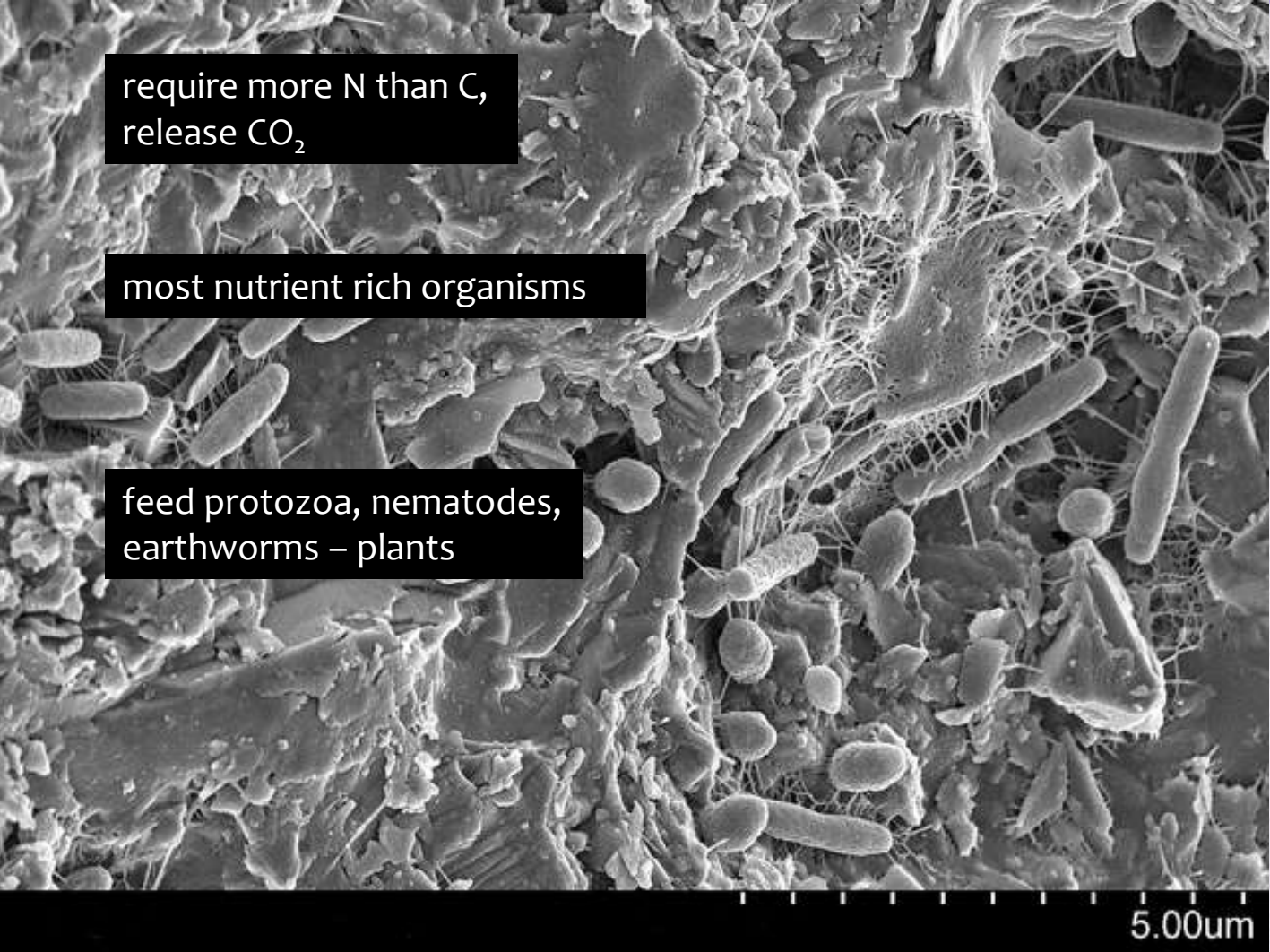
bacteria

require more N than C,
release CO₂

most nutrient rich organisms

feed protozoa, nematodes,
earthworms – plants

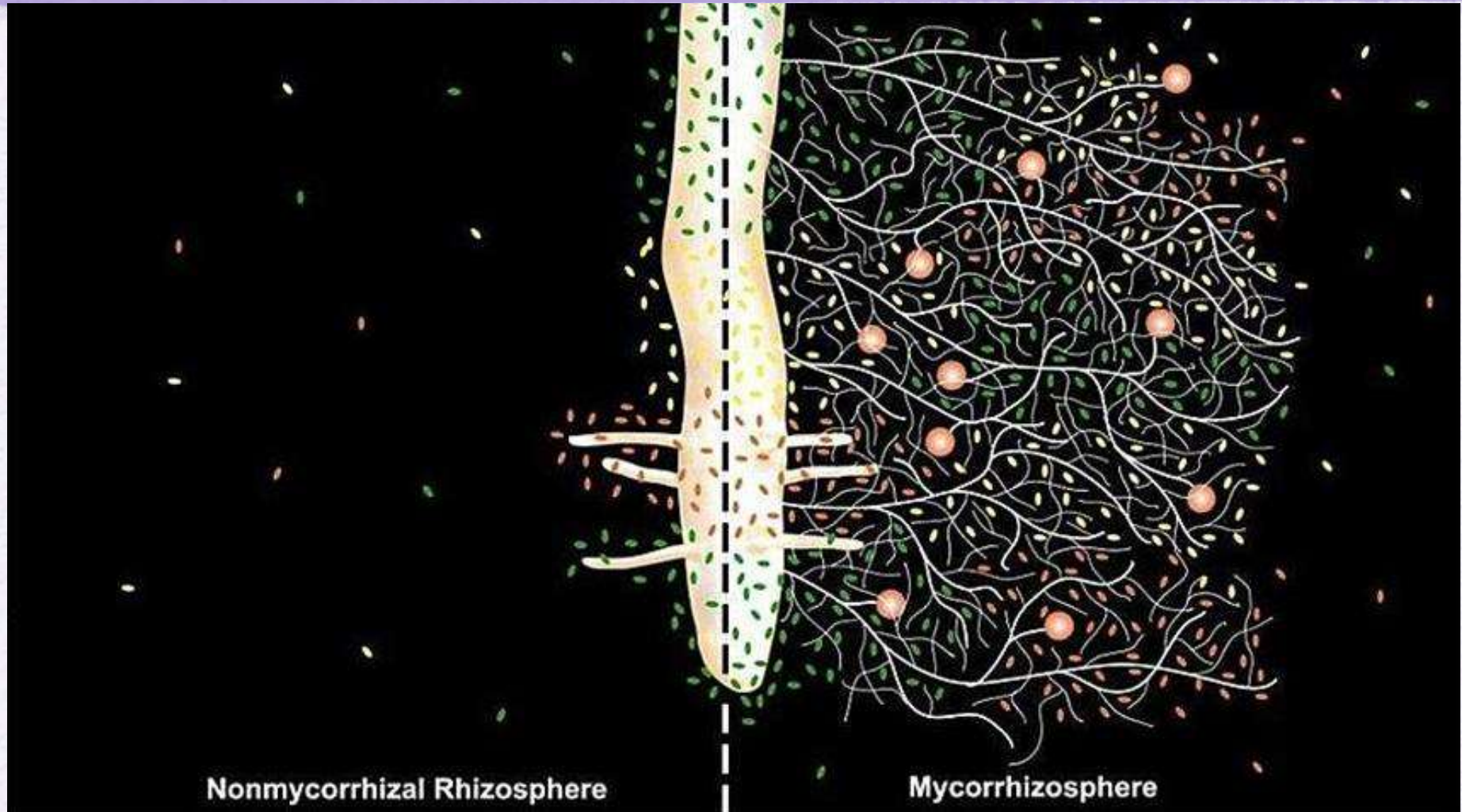
on a grain of sand
form
microaggregates



5.00um

SEM image: Anthony D'Onofrio,
William Fowle, Eric Stewart, and
Kim, Northeastern University

mycorrhizal microbiome



arbuscular mycorrhizal fungi

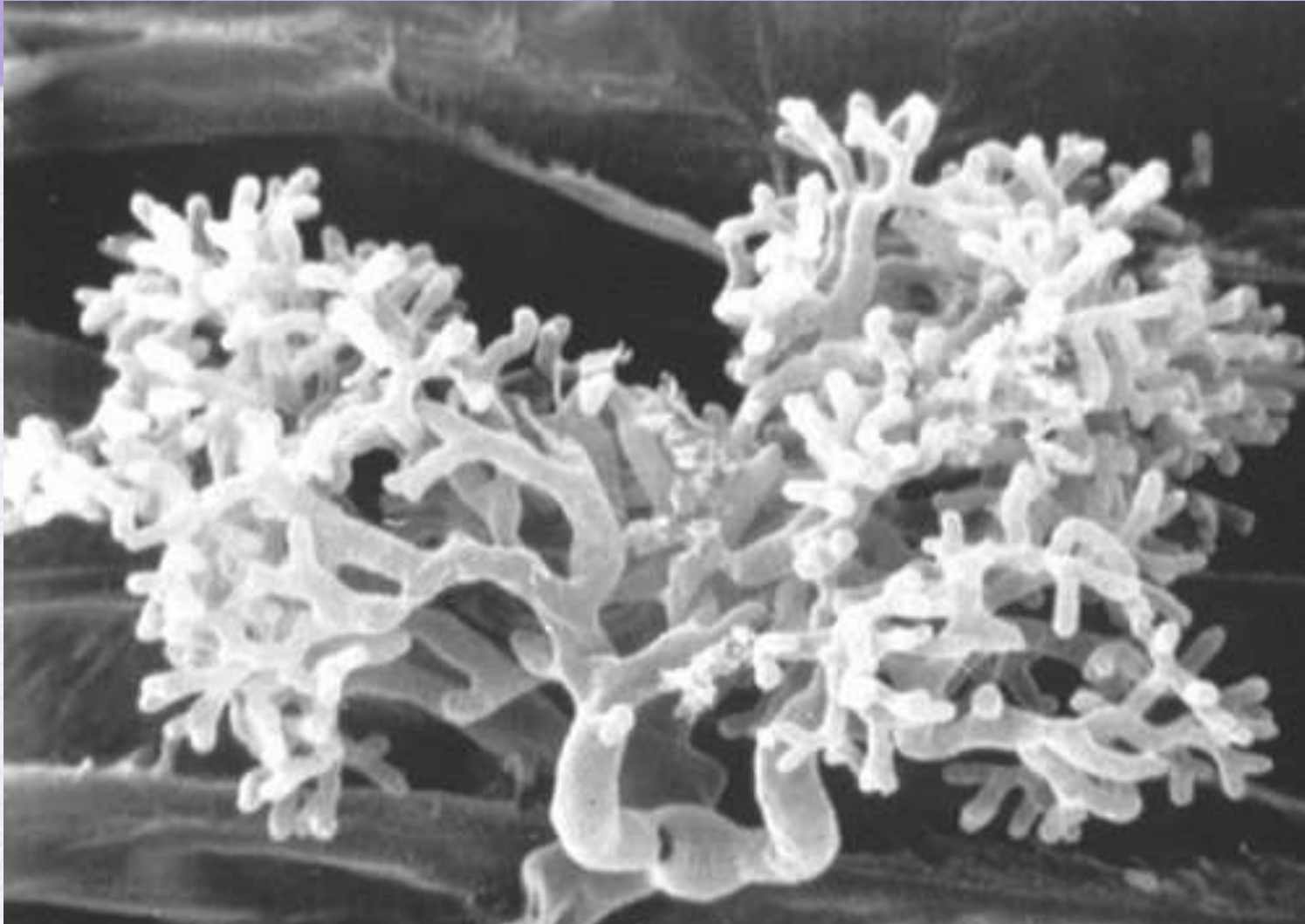


- symbiotic root extensions of ~80 - 92% of all plants (Wang & Qiu, 2006)
- 100 x more absorptive than roots
- 10-20% faster plant growth

Close-up of arbuscular mycorrhizal fungi connecting roots of plant hosts. Photo credit: Yoshihiro Kobae

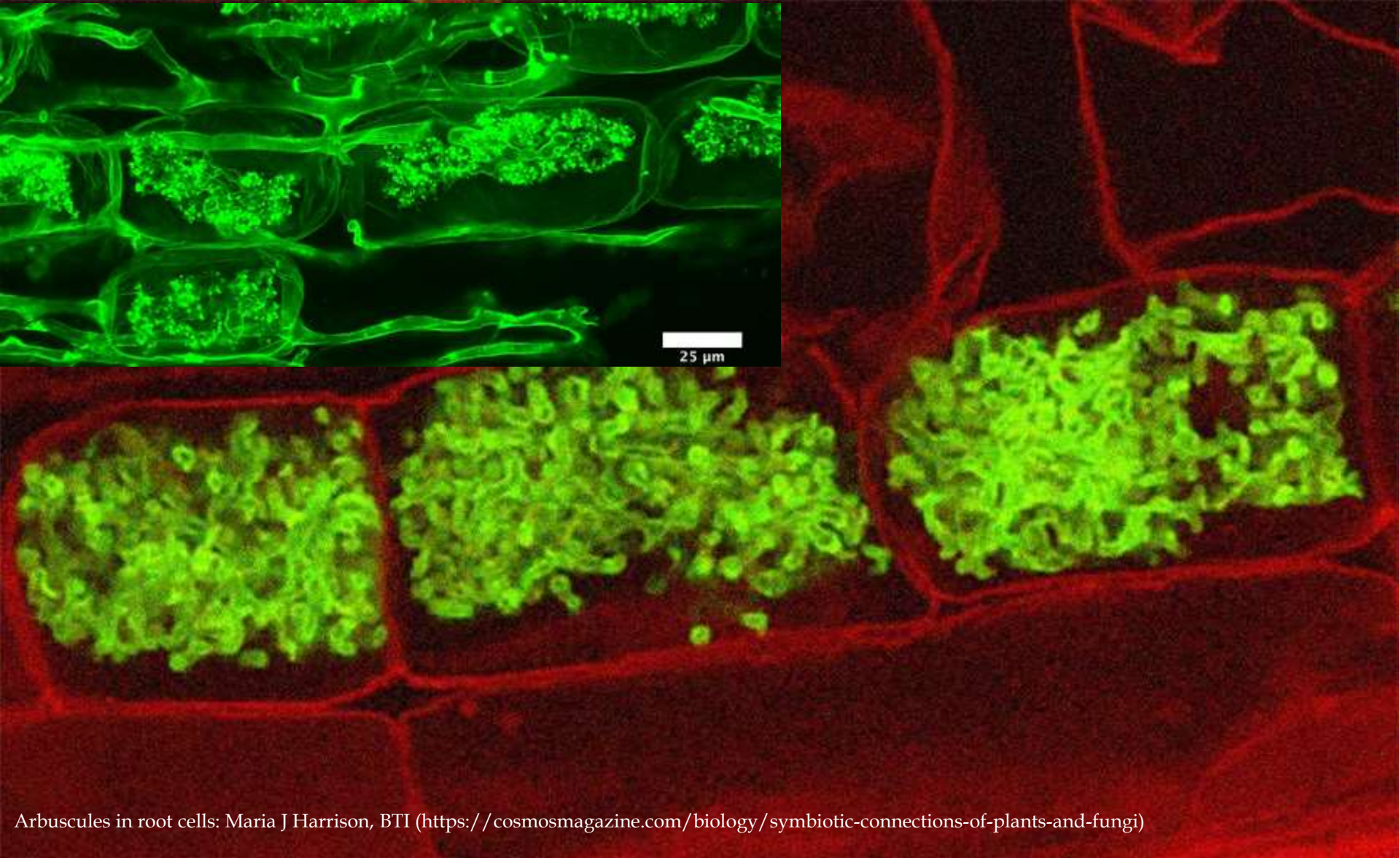
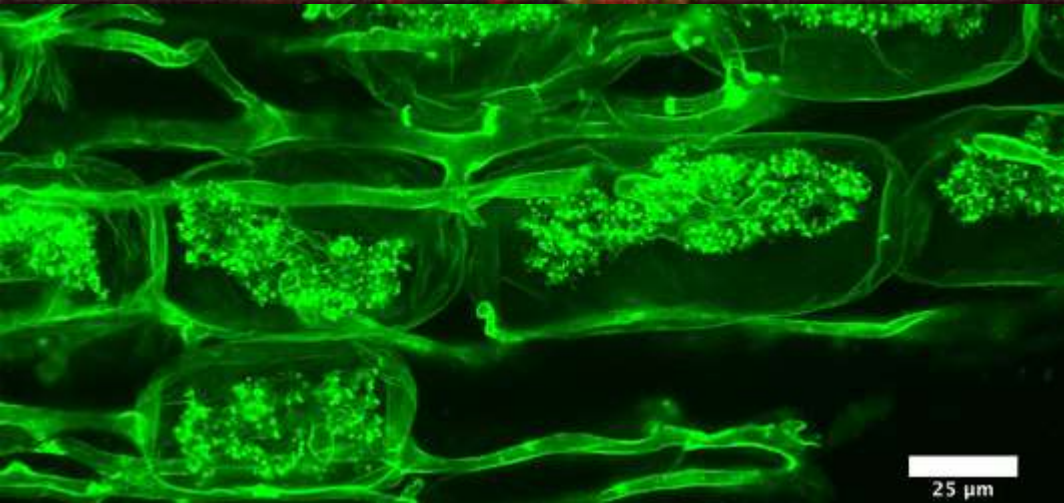
arbuscule

in root cortex



mycelium of 4m² of perennial grassland can stretch around the equator

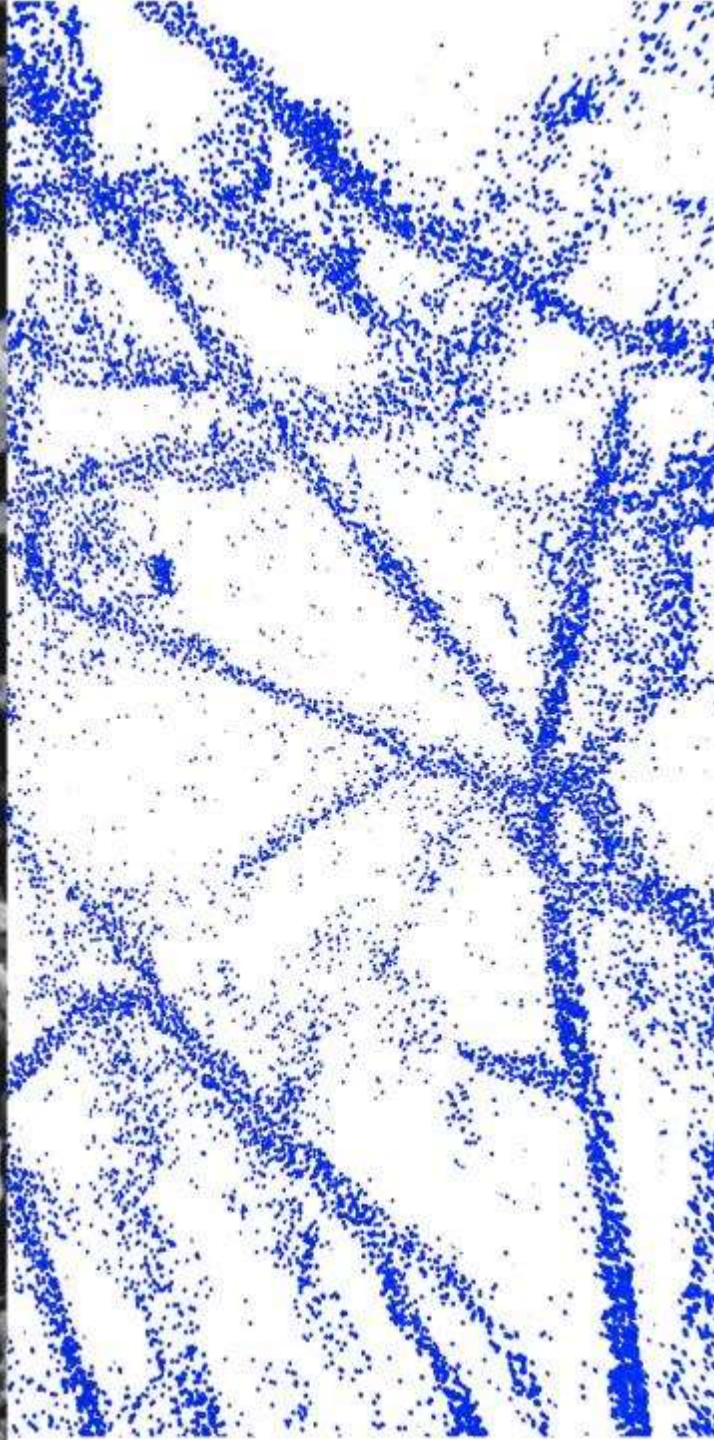
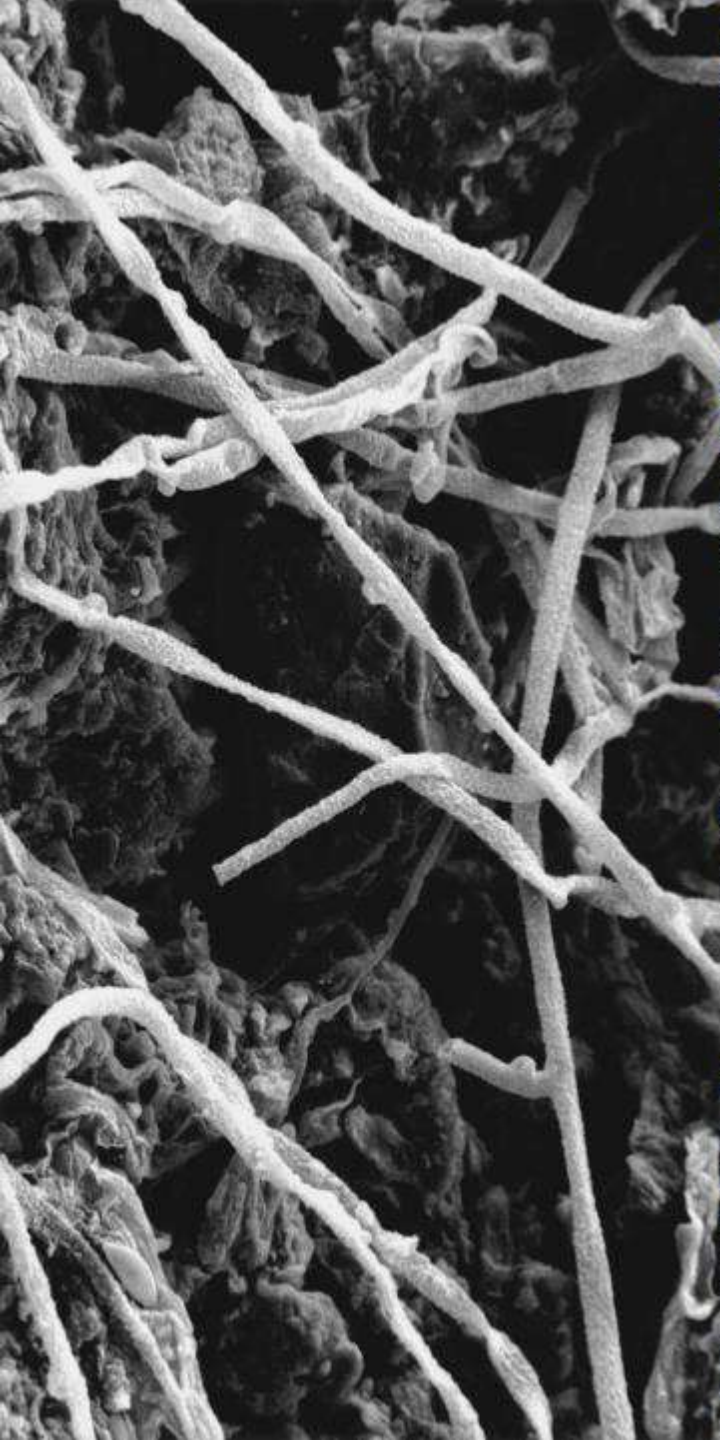
arbuscules





glomalin

glycoprotein containing 30–40% C assumed to be stable and persistent



carbon in hyphae

http://www.microped.uni-bremen.de/SEM_index.htm

fungi bind
micro-aggregates
into
macro-aggregates

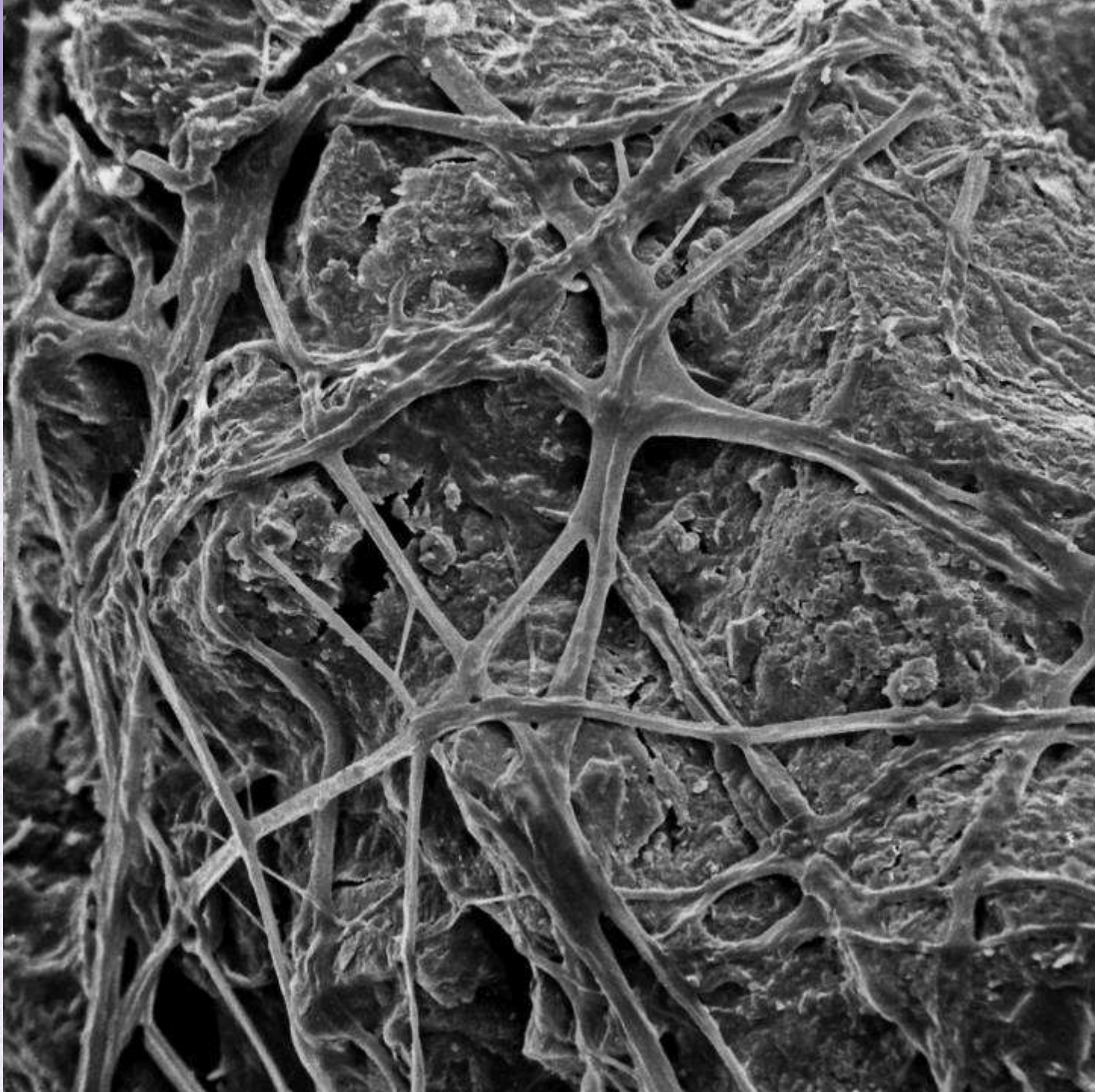


Image courtesy of Soil Microbial
Ecology, University of Bremen. <http://www.microped.uni-bremen.de>

mycorrhizal crops





difference between potatoes from untreated plants (l) and treated plants (r). Photo: Premier Tech Agriculture

saprophytic soil fungi

A microscopic image of a single, long, brownish hypha of a saprophytic soil fungus. The hypha is segmented and runs diagonally across the frame. The background is a light, grainy surface with numerous small, dark, irregular particles and some larger, more complex structures, likely soil organic matter or other microorganisms. Several black text boxes are overlaid on the image, providing information about the fungus and its role in the soil.

feed nematodes, micro and macro-arthropods, earthworms

coloured hyphae $>3.0 \mu\text{m}$

release plant available nutrients NH_4^+

decompose woody OM

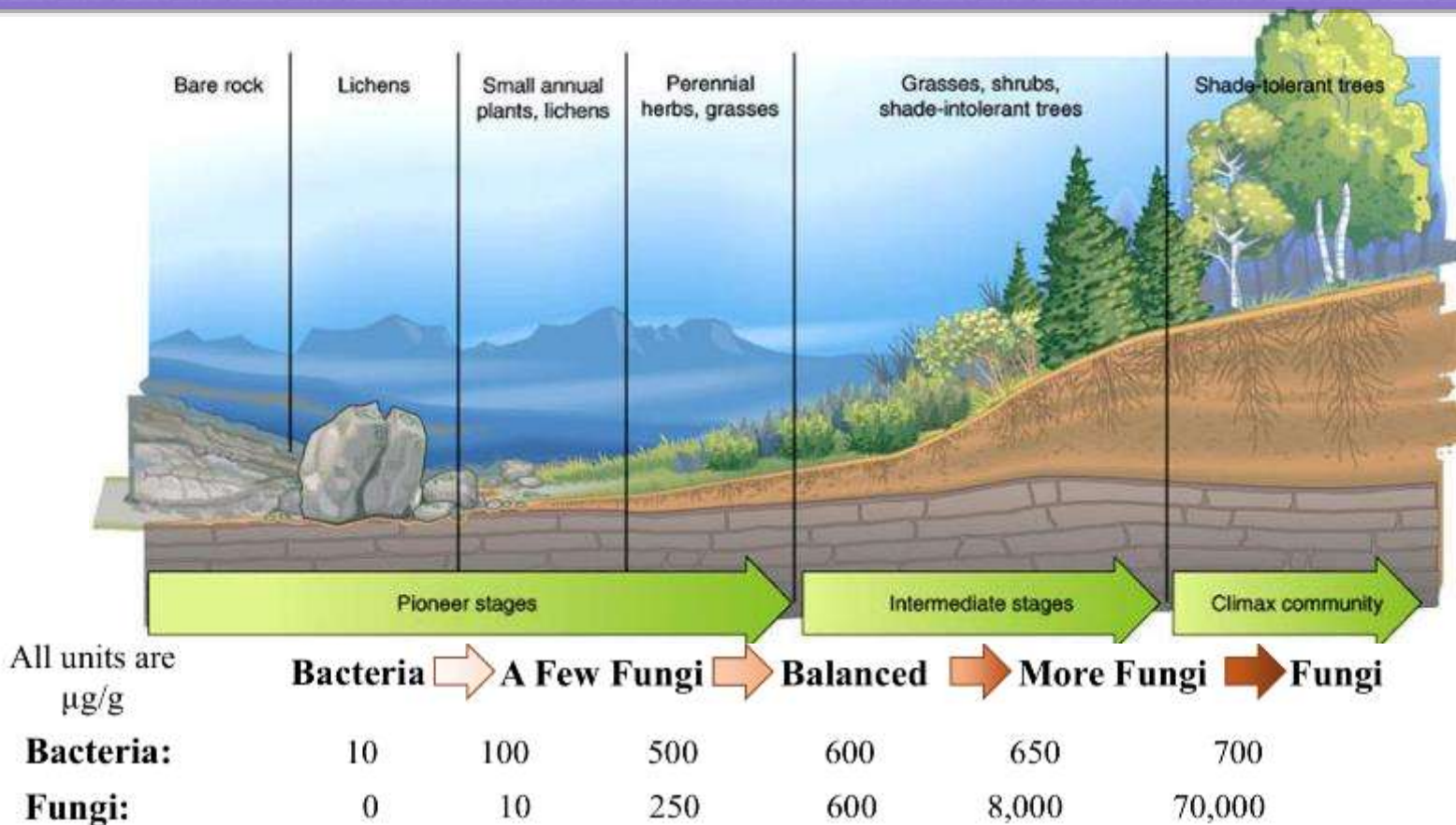
cell walls high C - fulvic and humic acids

develop later in succession

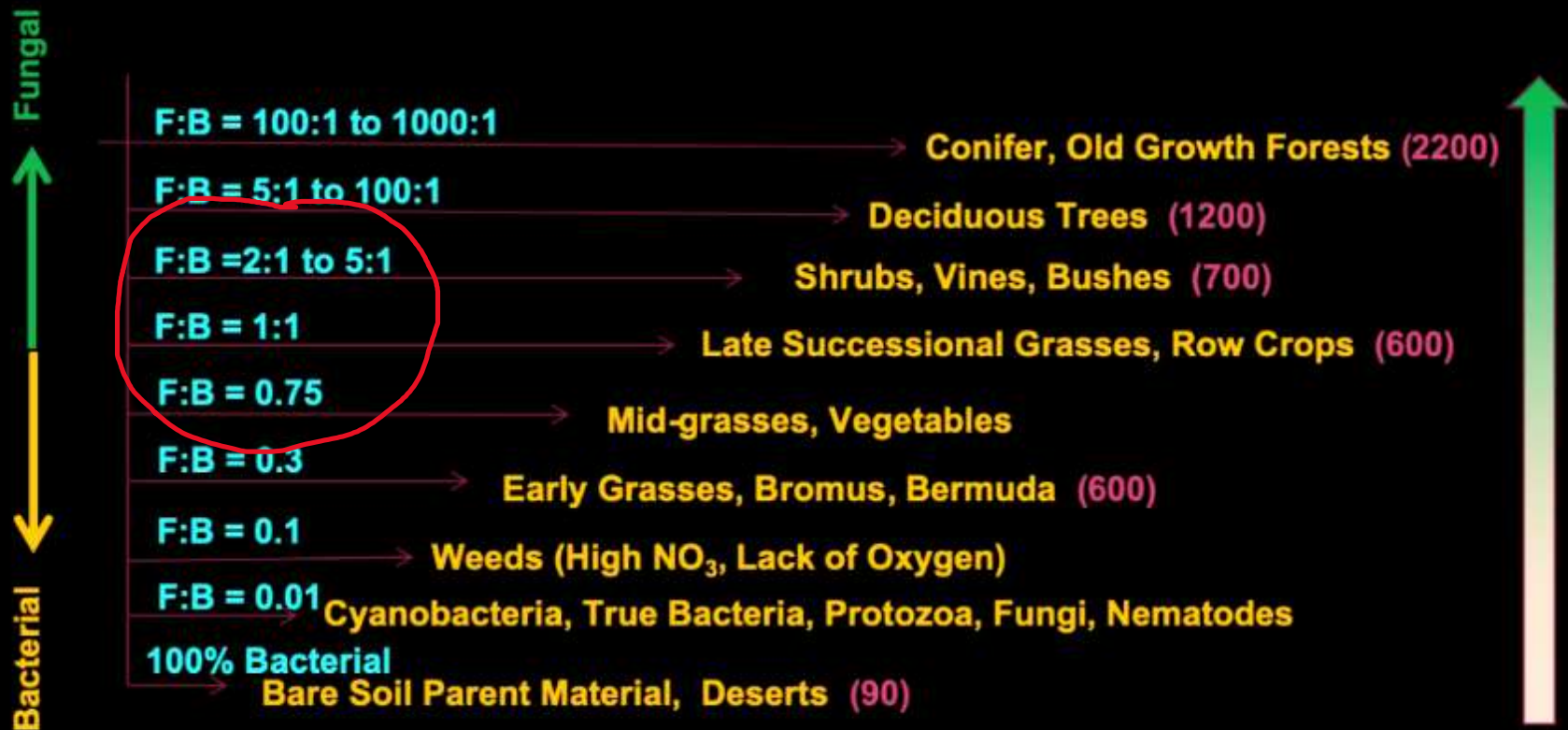
store and sequester C

bind aggregates – soil structure

fungals:bacterial biomass determines plant succession



Plant Succession Ladder as a Function of Fungal:Bacterial Ratio (F:B)



Elaine Ingham- [www. soilfoodweb.com](http://www.soilfoodweb.com)

protozoa

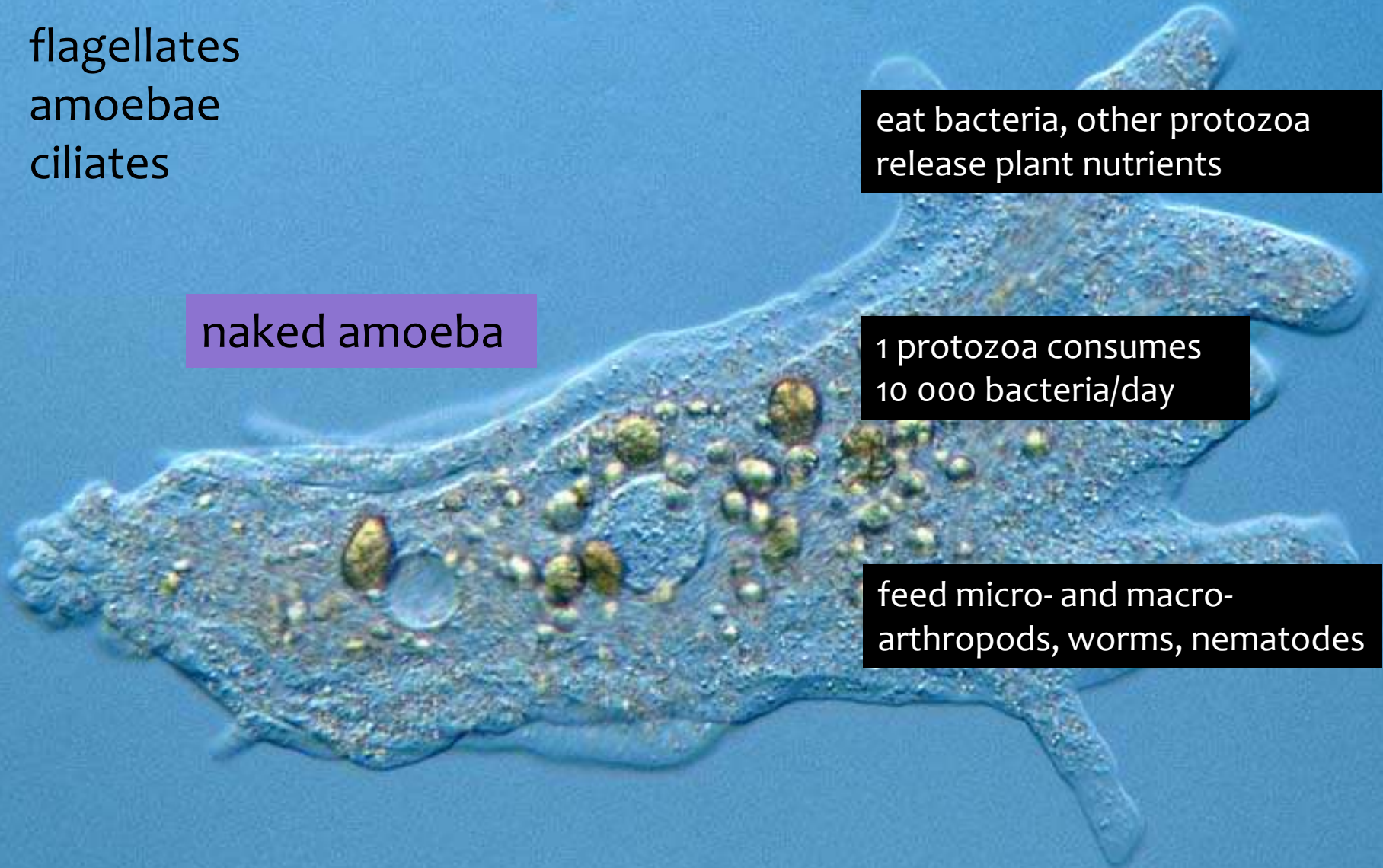
flagellates
amoebae
ciliates

naked amoeba

eat bacteria, other protozoa
release plant nutrients

1 protozoa consumes
10 000 bacteria/day

feed micro- and macro-
arthropods, worms, nematodes



a

Phagotrophy

Chemical communication

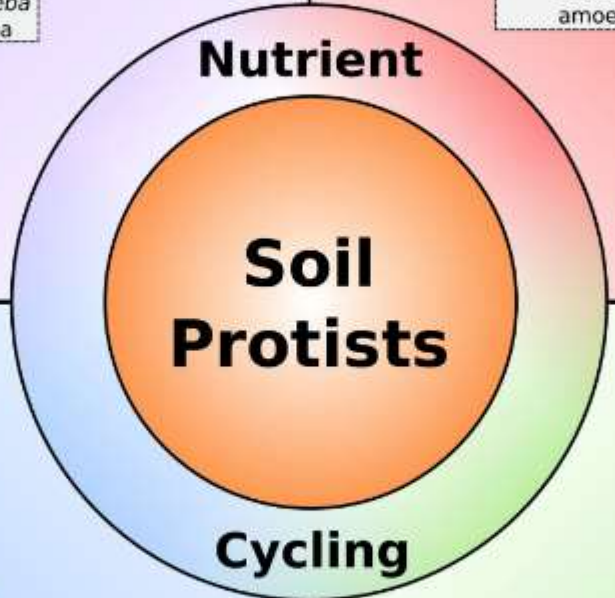
Population control

Symbiosis

Pathogenesis, Mutualism

b

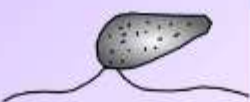
Geisen et al., Soil protists: a fertile frontier in soil biology research
FEMS Microbiology Reviews, 42, 2018, 293–323



Scuticociliatia
Ciliophora



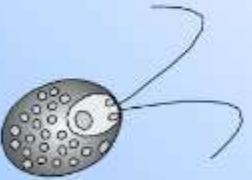
Acanthamoeba
Amoebozoa



Glissomonadida
Cercozoa



Neobodonida
Euglenozoa



Polytoma
Chlorophyceae



Dermamoebidae
Mycamoeba sp.



Free living
Oomycetes



Parasites of plants
(e.g. *Phytophthora*)



Mutualism (e.g. *Hyalosphenia*
amoeba with algae)



Parasites of fungi
(e.g. *Rozella*)



Parasites of metazoans
(e.g. *Haptoglossa*)



Botrydiaceae



Zygnematophyceae



Trebouxiophyceae



Bacillariophyceae

c

Saprotrophy

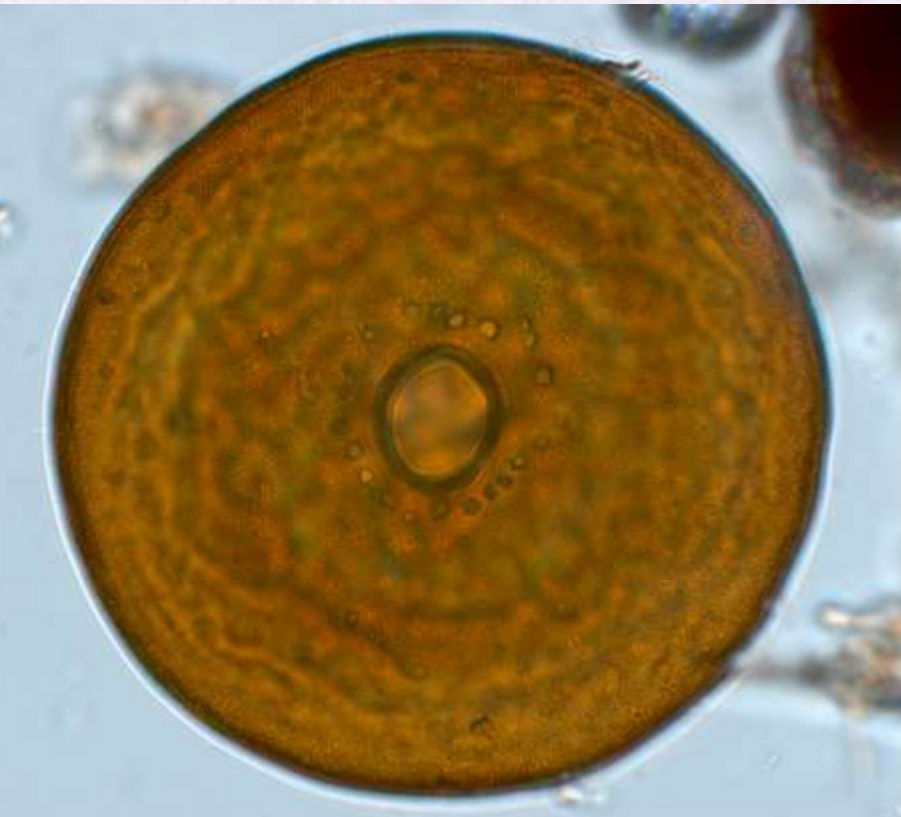
Organic matter degradation

Phototrophy

Carbon fixation

d

testate amoebae



flagellates



ciliates: reduced oxygen/anaerobic



nematodes

80 percent of all animals on Earth

consume bacteria, fungi,
protozoa and nematodes
release plant available nutrients

feed micro- and macro-arthropods,
earthworms and nematode-trapping fungi



nematode –
releasing plant
available
nutrients

nematodes

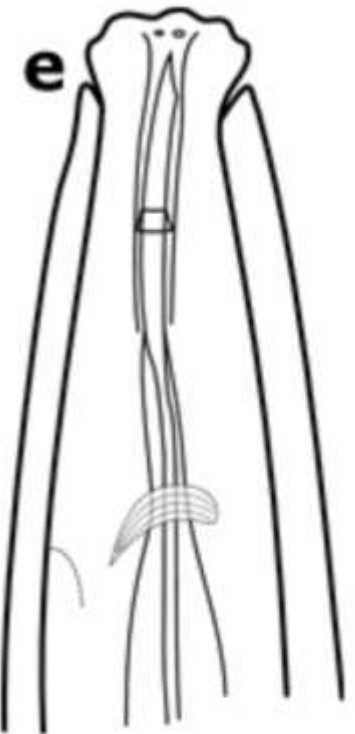
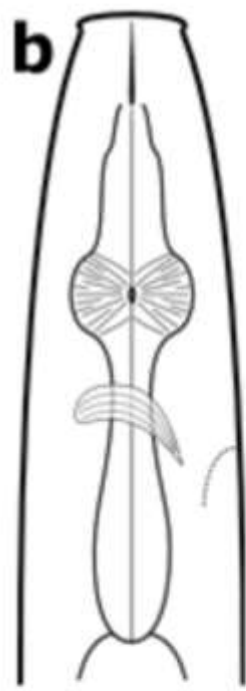
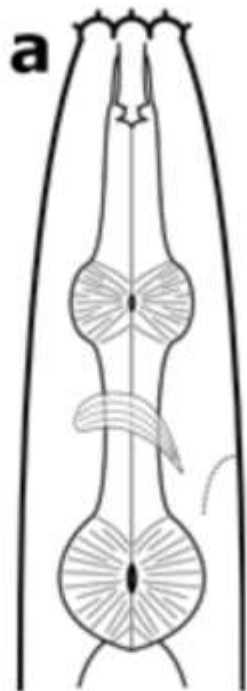
Bacterial

Fungal

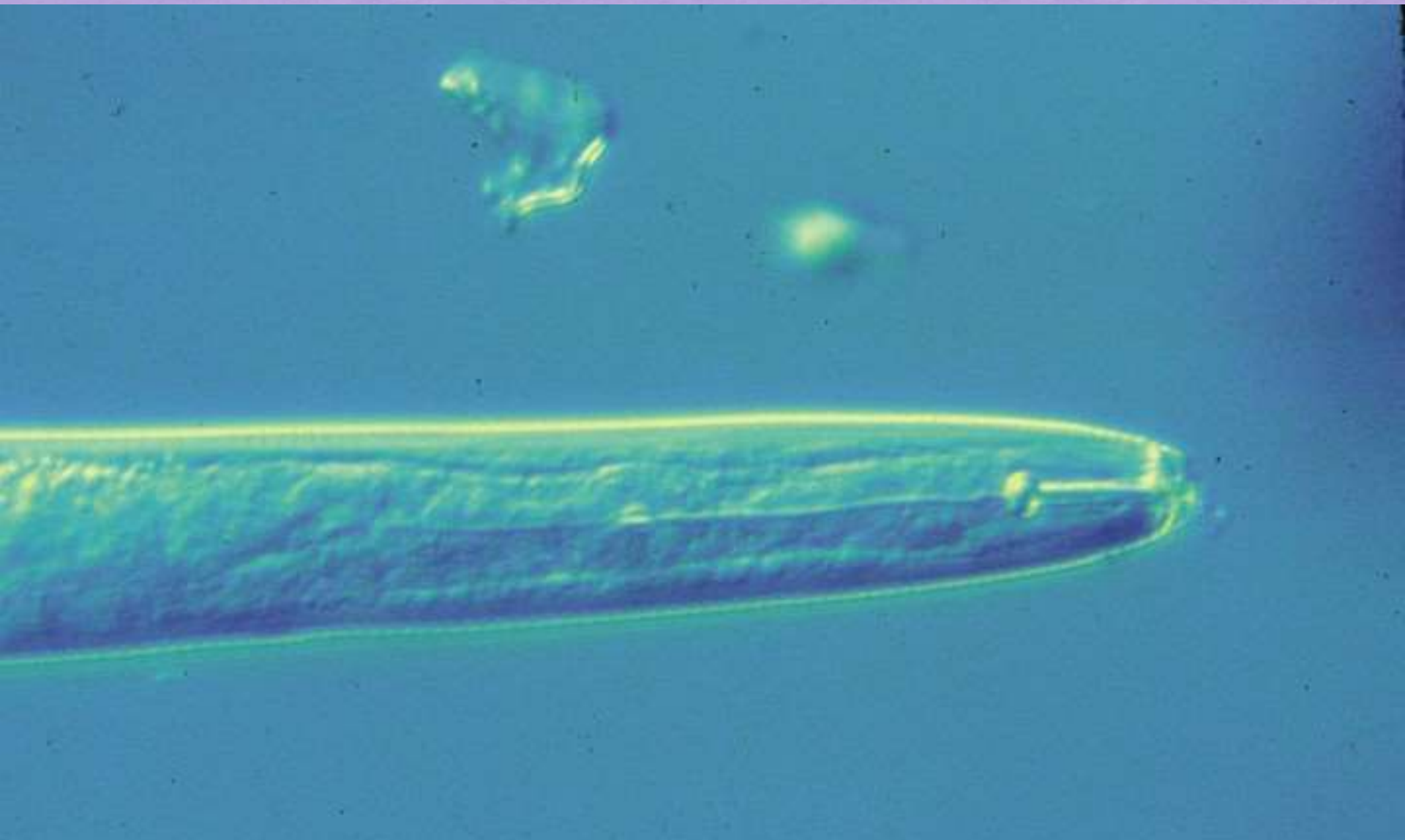
Root

Predatory
(Fungal)

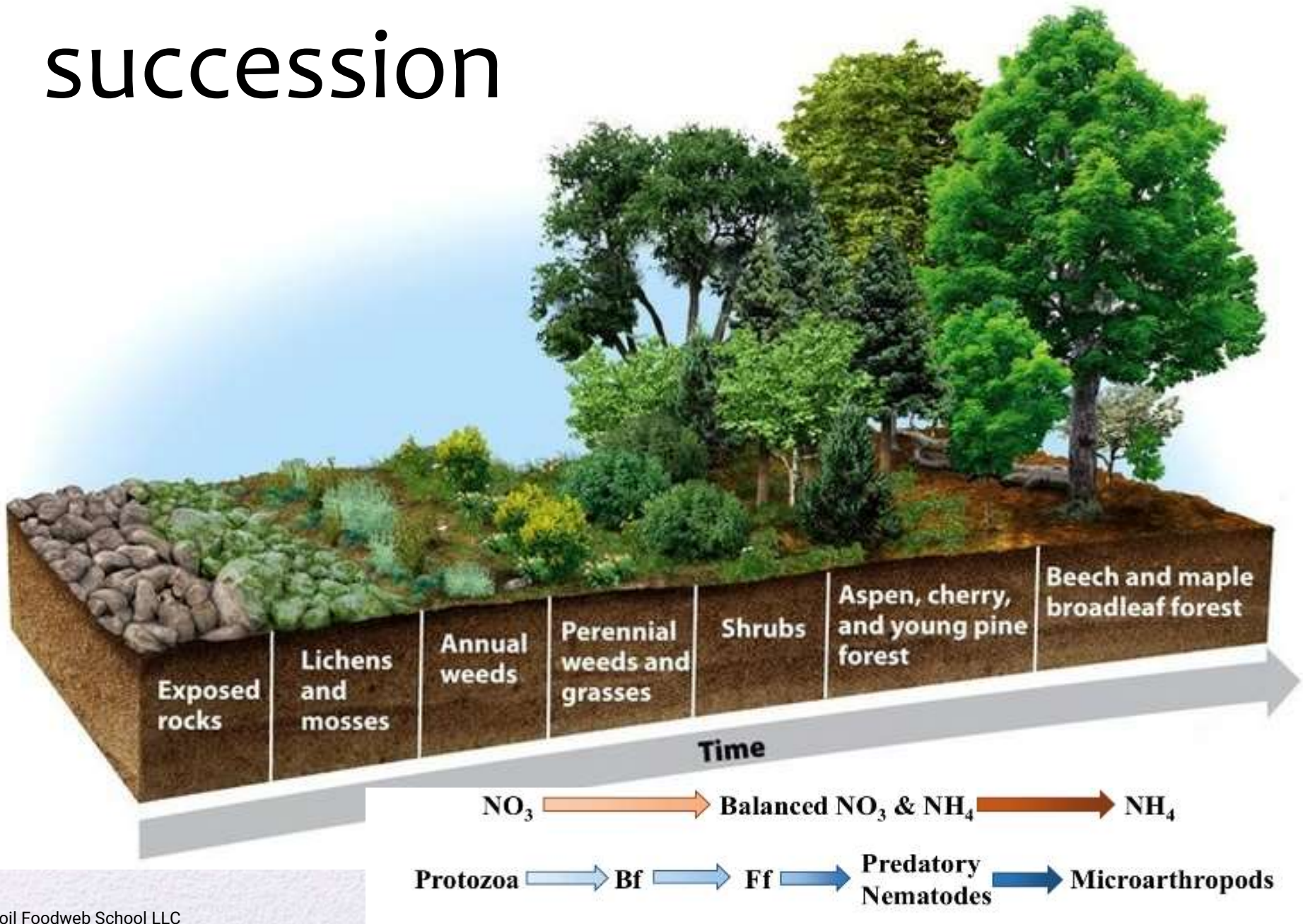
Omnivore



root feeding nematode



succession



functional soil food web

organisms	minimal requirements/g soil
bacteria	135ug
actinobacteria	<16ug
fungi	135ug
protozoa (flagellates and amoebae)	10 000
ciliates	<100
nematodes	>100

application results

Organisms	Agricultural Field	BioComplete™ Compost (1 ton/ac)	Two weeks later
Total bacteria (µg/g dry soil)	135	900	360
# bacterial sp/g soil (DNA)	5,000	75,000	75,000
Total fungi (µg/g dry soil)	2 (i.e., dirt)	428	293
# fungal species /g soil (DNA)	500	25,000	25,000
Protozoa: F, A C	0, 0 1,450	12,000, 31,000 29	6,000, 17,000 67

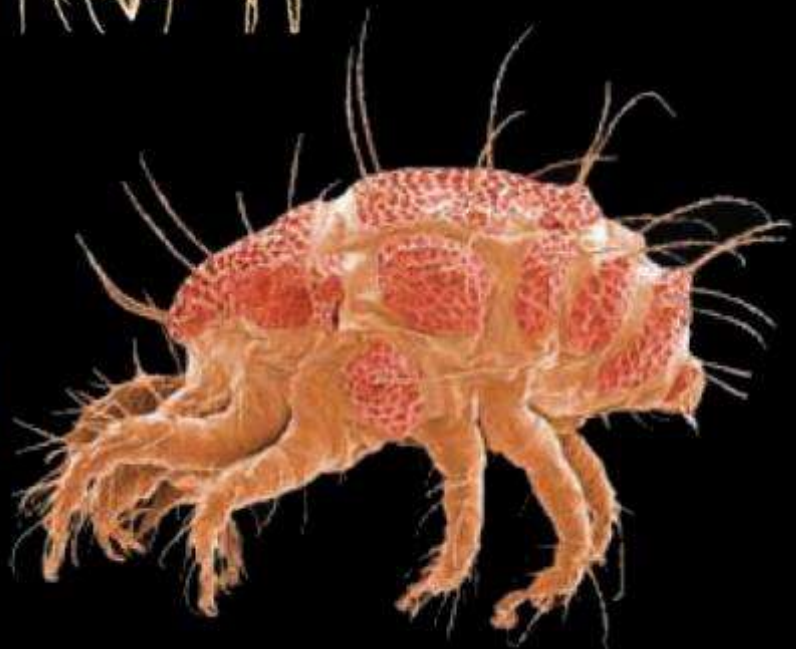
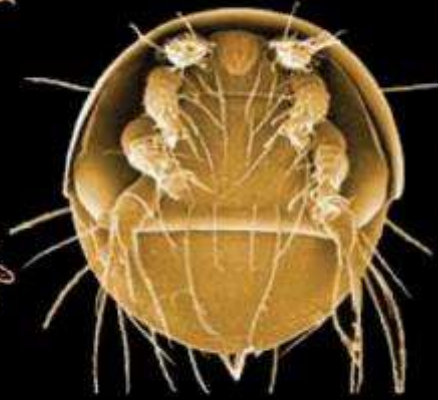
earthworms

consume, cultivate and disseminate microbes

soil nutrition – 7x N, 11x P



mites





heavily tilled

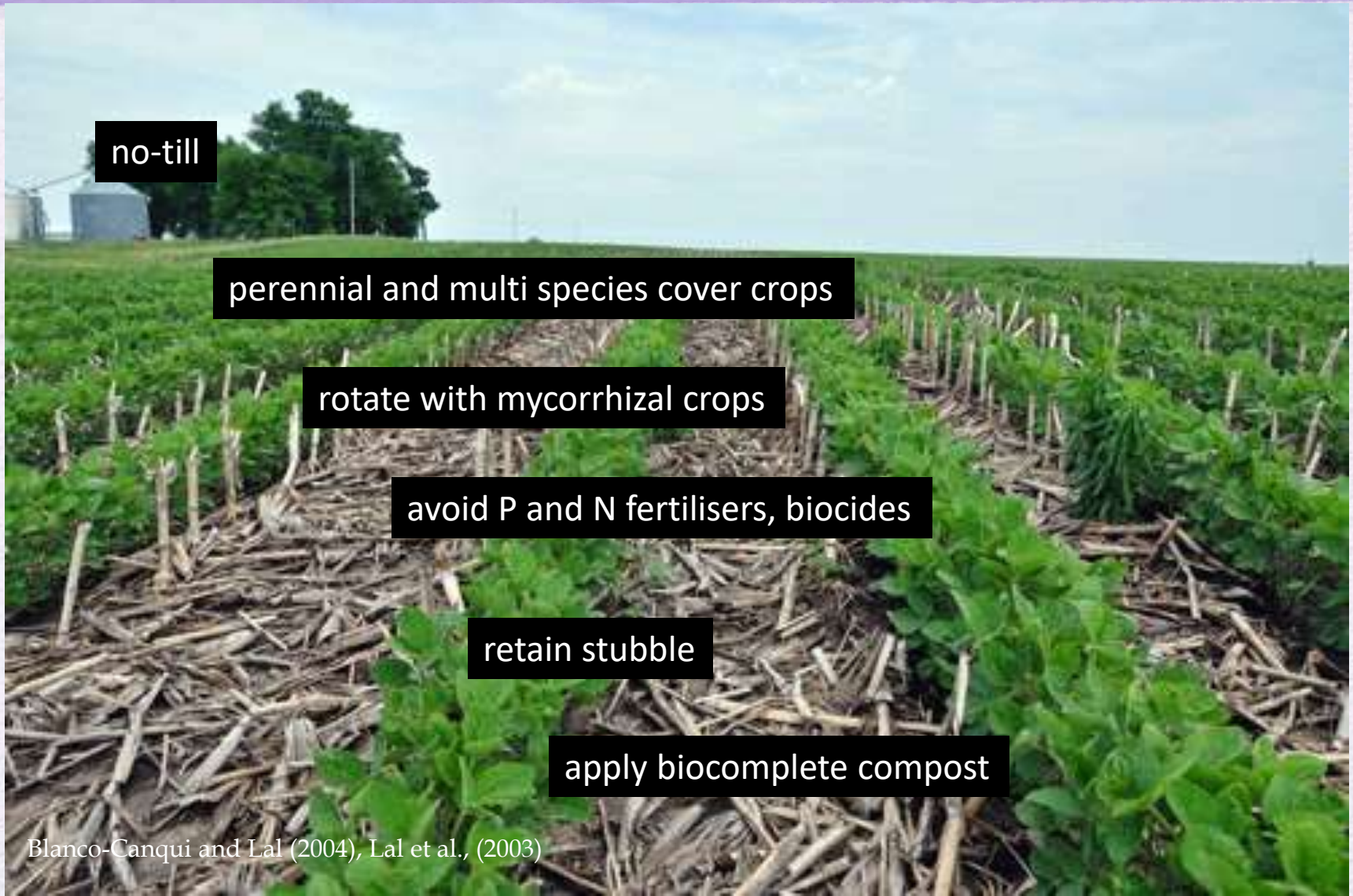
compost plus plants

natural untouched
pasture

soil restoration

- using biocomplete
compost amendments
- vermicompost
 - hot compost
 - Johnson-Su bioreactor

beneficial cultivation practices



no-till

perennial and multi species cover crops

rotate with mycorrhizal crops

avoid P and N fertilisers, biocides

retain stubble

apply biocomplete compost

Jacaranda Hill soil biology and multispecies cover crop trial report



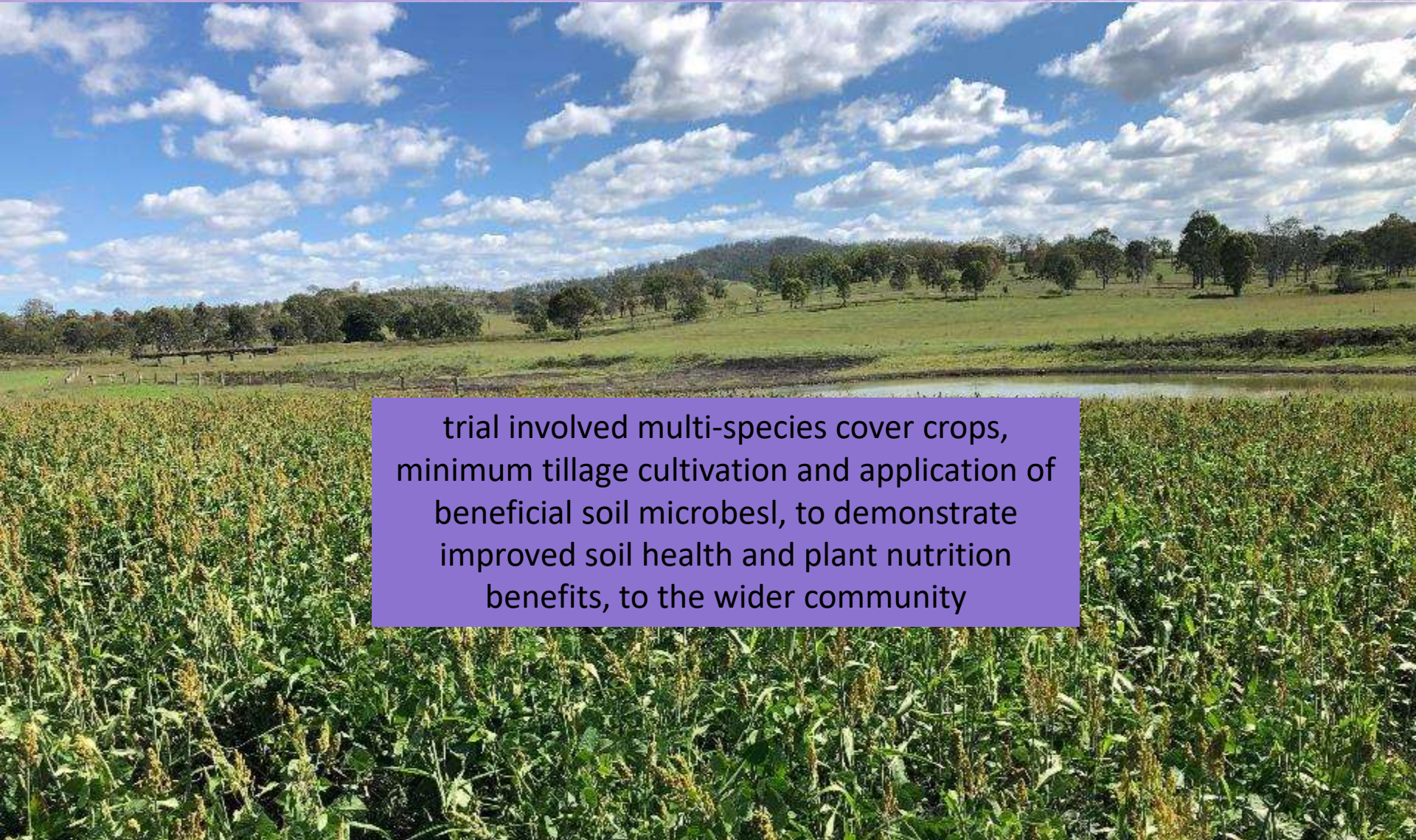
Sandra Tuszynska (PhD)

BSciAg - soil biologist (microbiology, mycology, certified soil food web technician)

- Reg Pease (land manager)
- Bruce Lord and HLW
- Markus Kerkdijk

On-farm soil microbiome restoration and cover crop trial Brisbane Valley Kilcoy Landcare project

Supported by Healthy Land and Water, Community NRM Activity Support Grants



trial involved multi-species cover crops, minimum tillage cultivation and application of beneficial soil microbes, to demonstrate improved soil health and plant nutrition benefits, to the wider community

trial aims

to improve soil

- biodiversity
- structure
- water holding capacity
- resistance to drought, pests and diseases



summary of activities and observations

- Thermal compost and worm farm cultivation of beneficial soil microbes
- Millet vs multispecies cover crop (8 species mix)
- November - application of compost and castings extract to seeds and soil, post sowing (hot, dry weather, minimal irrigation)
- December and March - additional extract applications to treatment crop
- Crops struggle without rain, millet monocrop poor growth, eventually strip grazed
- Multispecies cover crop takes off after March rains, especially treatment plot
- Marked difference observed in biomass and photosynthetic output of treated crop vs control
- Biological assessment did not reveal a marked soil food web organism increase, however active rhizobium nodules and root symbiotic fungi present on roots of treated crop
- Bacterial diversity increase and quorum sensing is likely to have increased and presence of bacterial predators indicates nutrient cycling

biocomplete compost preparation



cow manure



cow manure



mixerbin: cow manure, chicken manure, wood chip, silage, straw in correct proportions



loading mixerbin :
to achieve desired C:N ratio



welding compost bioreactor cage



compost bioreactor on a pallet



regular temperature testing of compost to prevent overheating and anaerobic conditions



when compost reaches 75C° it must be turned



turning hot compost while monitoring moisture



chimneys added to prevent anaerobic conditions forming from bacterial overgrowth



microscopy
analysis of
maturing
compost



compost microbiome

A microscopic view of a compost microbiome. The image shows a dense population of various microorganisms. A large, oval-shaped organism with a thick, multi-layered shell and a granular interior is the central focus. It has a long, thin, hair-like appendage extending from one end. Surrounding it are numerous smaller, more diverse organisms, including many tiny, rod-shaped bacteria and other smaller protozoa. The background is a light, slightly hazy grey, typical of a wet mount slide.

protozoa – testate amoeba (400x magnification)
consume bacteria releasing plant available nutrients

tiny bacteria (1 micron)
most nutrient rich organisms on Earth

A microscopic image of a compost microbiome. The field is filled with numerous small, spherical microorganisms, likely ciliates or other protists. Two purple arrows point from a central purple box labeled 'testate amoeba' to two specific organisms. The organism on the left is a large, oval-shaped testate amoeba with a distinct, multi-layered shell and a large, circular nucleus. The organism on the right is a smaller, more complex structure, possibly another type of microorganism or a different stage of the same organism. The background is a light, greyish-blue color, typical of a wet mount slide.

testate amoeba

compost microbiome

compost microbiome



protozoa -
arcella

(400x magnification)
consume bacteria releasing plant
available nutrients

protozoa -
cercazoa

The image shows a microscopic view of a compost microbiome. A large, dark, circular Arcella is the central focus, with a purple arrow pointing to it from the right. Below it, a smaller, lighter-colored Cercazoa is also pointed to by a purple arrow from the right. The background is filled with various other microorganisms and organic matter, appearing as a complex, textured field of colors including browns, greys, and yellows.

(400x magnification)
consume bacteria releasing plant
available nutrients

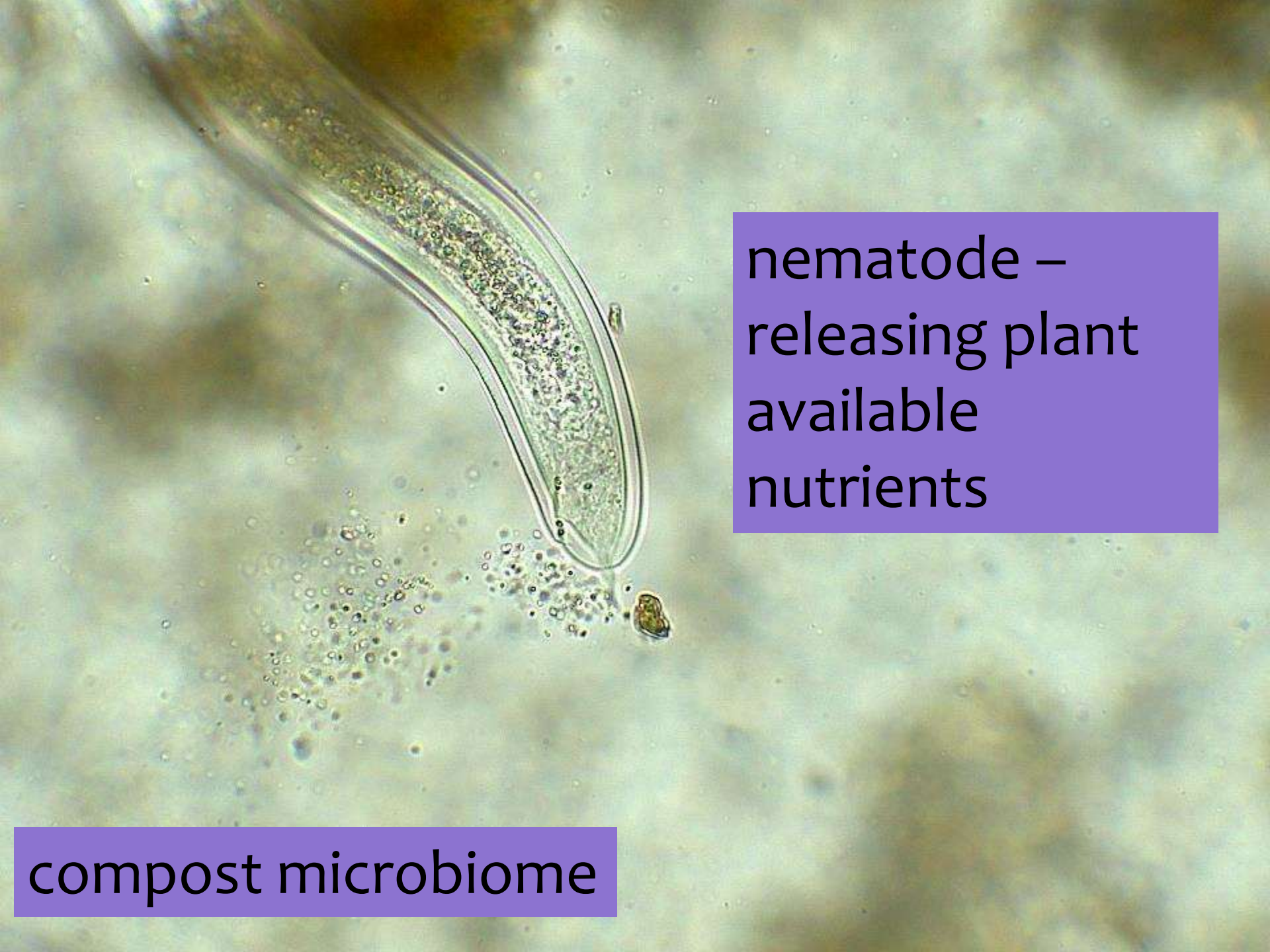
protozoa -
cercazoa

compost microbiome

A microscopic image of a compost microbiome. A large, clear, cylindrical nematode with distinct transverse segments is the central focus. It is surrounded by a complex environment of organic matter, including dark brown clumps of soil or compost, and numerous small, circular and irregular particles, likely bacteria and protozoa. The background is a light, yellowish-brown color, suggesting a moist, nutrient-rich environment.

omnivorous
nematode

(400x magnification)
consume bacteria, protozoa and
smaller nematodes, releasing
plant available nutrients

A microscopic image showing a nematode, a small, worm-like animal, positioned vertically. The nematode's body is filled with numerous small, dark, granular particles, which are likely plant available nutrients. The nematode is shown in the process of releasing these nutrients, as a cluster of these particles is visible at its posterior end. The background is a light, textured surface, possibly soil or compost.

nematode –
releasing plant
available
nutrients

compost microbiome



fungal hypha

(400x magnification)
sequester carbon into fulvic and
humic acids (brown colour)

require organic matter
to proliferate

compost microbiome

A microscopic view of a compost microbiome. The image shows a dense population of various microorganisms, including numerous small, round spores and larger, irregularly shaped fungal hyphae. A prominent, long, thin, segmented hypha is visible in the center-right. The background is a light, yellowish-brown color, typical of compost.

beneficial
fungal hypha

increasing fungal
biomass in soil
provides ammonium
to plants, selecting
against weeds, which
prefer nitrate

compost microbiome

functional soil food web

organisms	minimal requirements/g soil
bacteria	135ug
actinobacteria	<16ug
fungi	135ug
protozoa (flagellates and amoebae)	10 000
ciliates	<100
nematodes	>100

Our compost surpassed these minimal values

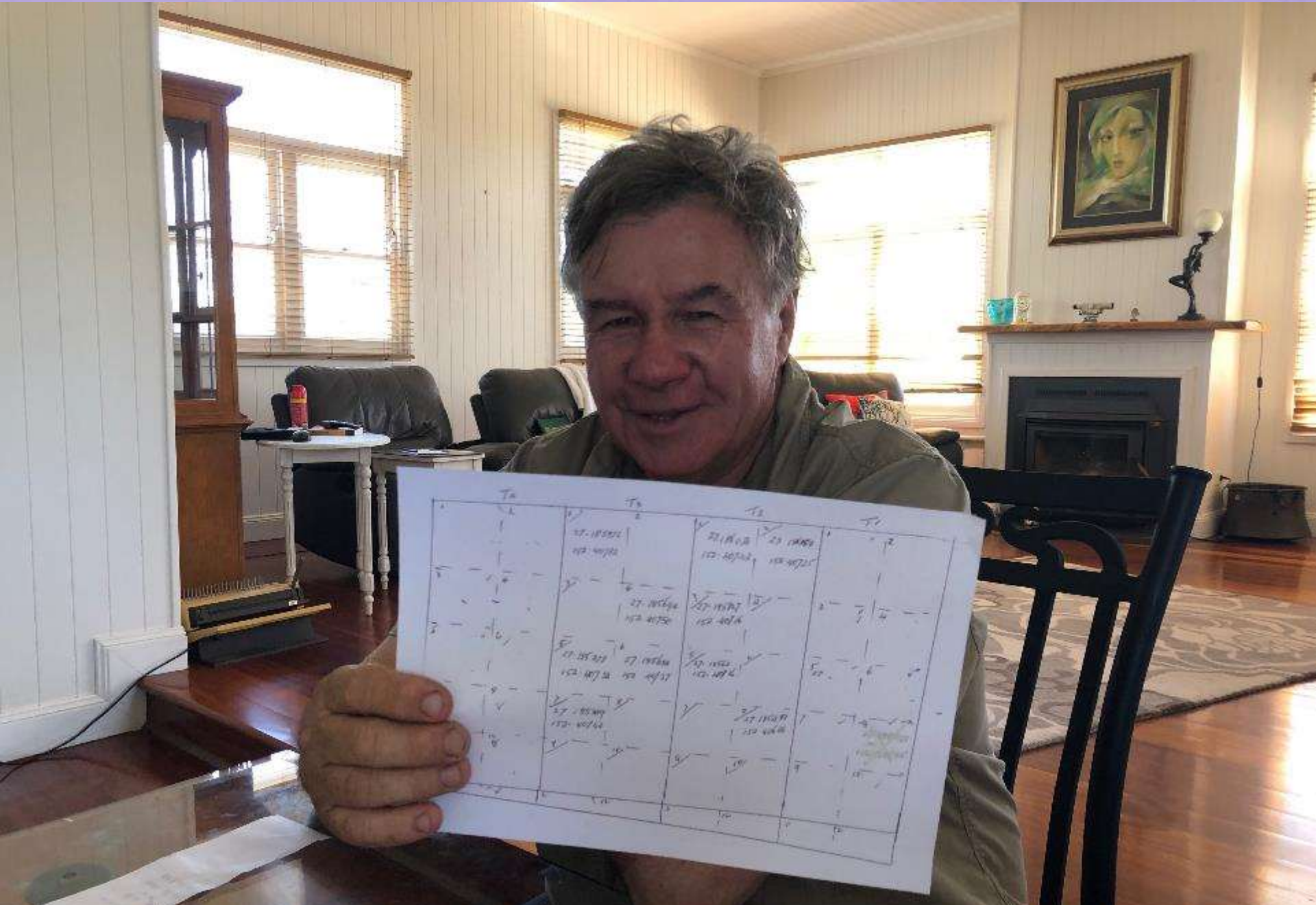
soil food web microbial analysis report of compost

Beneficial Microorganisms	Sample Results	Detrimental Microorganisms	Sample
Bacterial Biomass ($\mu\text{g/g}$)	416.884	Oomycetes Biomass ($\mu\text{g/g}$)	54.563
Bacterial Standard Deviation Biomass ($\mu\text{g/g}$)	98.912	Oomycetes Standard Deviation Biomass ($\mu\text{g/g}$)	25.787
Bacterial Standard Deviation as Percentage of Mean	23.70%	Oomycete Standard Deviation as Percentage of Mean	47.30%
Actinobacterial Biomass ($\mu\text{g/g}$)	0.707	Oomycetes Average Diameter - Weighted Mean (μm)	1.615
Actinobacterial Standard Deviation Biomass ($\mu\text{g/g}$)	0.585	Ciliates (number/g)	62408.0
Actinobacterial Standard Deviation as Percentage of Mean	82.70%	Ciliates Standard Deviation (number/g)	56970.0
Fungal Biomass ($\mu\text{g/g}$)	969.841	Ciliates Standard Deviation as Percentage of Mean	91.30%
Fungal Standard Deviation Biomass ($\mu\text{g/g}$)	437.203	Root-feeding Nematodes (number/g)	0
Fungal Standard Deviation as Percentage of Mean	45.10%		
Fungal Average Diameter - Weighted Mean (μm)	4.872		
F:B Ratio	2.322		
Total Beneficial Protozoa (number/g)	520065.0		
Total Beneficial Protozoa Standard Deviation (number/g)	314915.0		
Total Beneficial Protozoa Standard Deviation as Percentage of Mean	60.60%		
Flagellates (number/g)	187223.0		
Flagellates Standard Deviation (number/g)	174392.0		
Flagellates Standard Deviation as Percentage of Mean	93.10%		
Amoebae (number/g)	332842.0		
Amoebae Standard Deviation (number/g)	154276.0		
Amoebae Standard Deviation as Percentage of Mean	46.40%		
Bacterial-feeding Nematodes (number/g)	630.0		
Fungal-feeding Nematodes (number/g)	105.0		
Predatory Nematodes (number/g)	105.0		

Export Soil Biology Report Help Exit

fungal to bacterial biomass ratio of 1:1 is enough to grow healthy crops

27th November, 2020 – trial map and planning



T1	T2	T3	T4
27-11-20 172-40720	27-11-20 172-40720	27-11-20 172-40720	27-11-20 172-40720
27-11-20 172-40720	27-11-20 172-40720	27-11-20 172-40720	27-11-20 172-40720
27-11-20 172-40720	27-11-20 172-40720	27-11-20 172-40720	27-11-20 172-40720
27-11-20 172-40720	27-11-20 172-40720	27-11-20 172-40720	27-11-20 172-40720

modifying machinery to suit compost extract application



modifying sprayer positions to deliver extract onto dropped seed





compost and worm farm castings
for seed and soil inoculation

8 x seed cover crop mix



Sunflower 3%
Buckwheat 8%
Chicory 7%
Sorghum 19%
Cowpea 27%
Lucerne 6%
Lablab 27%
Radish 3%

seed inoculant prep (molasses, water and milk mix)



seed inoculation and mixing



seed spreading



seed drying



we hand extracted microbes from the compost
but compost tea brewers can be used

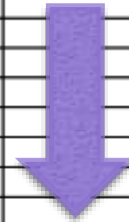


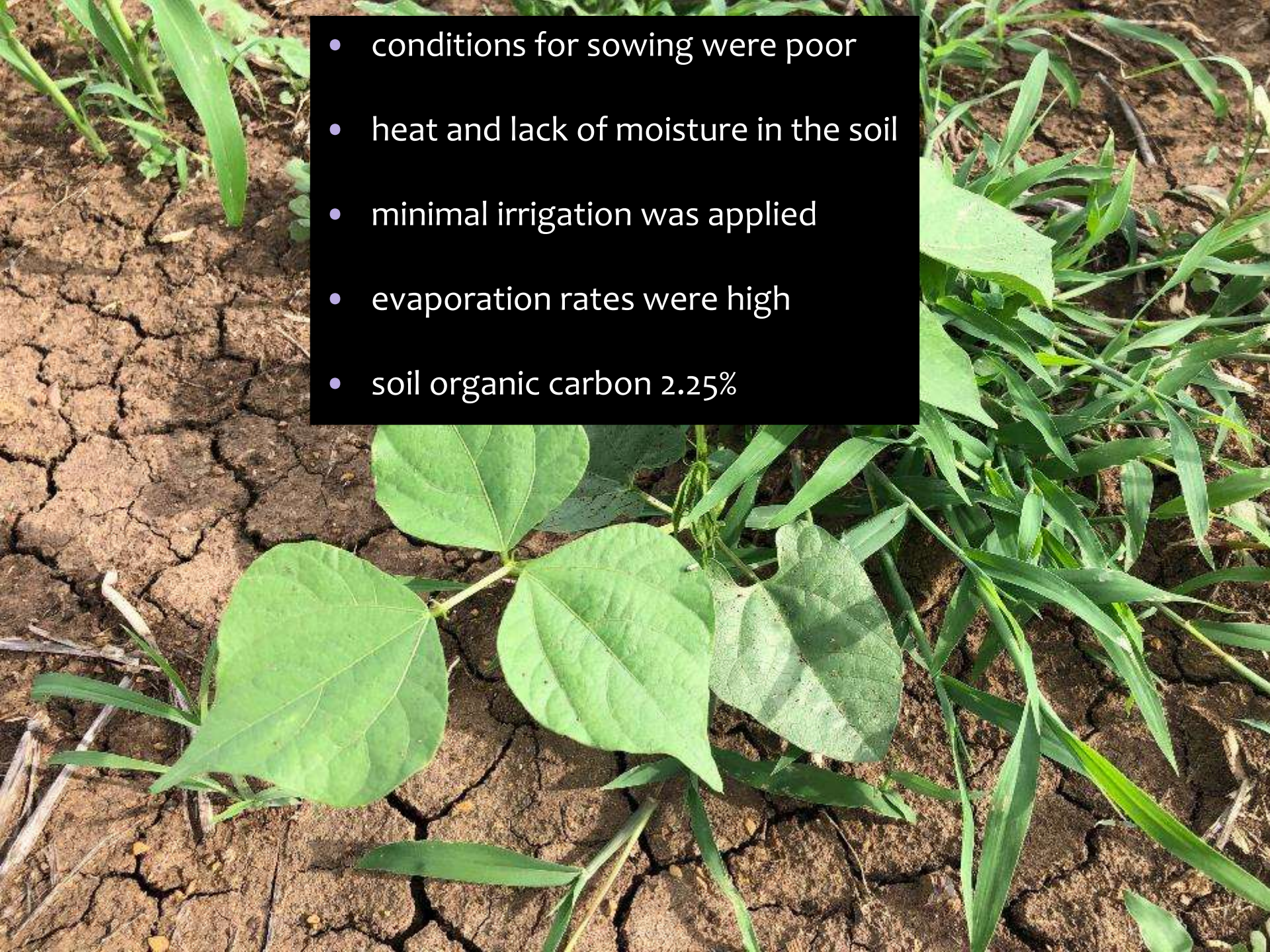
lack of soil moisture and ~40C° were unfavorable for sowing

Rainfall Registration For Jacarandahill 2020

From 9 am to 9 am daily

January mm	February mm	March mm	April mm	May mm	June mm	July mm	August mm	September mm	October mm	November mm	December mm	Date
												1
												2
	5											3
	11											4
	20			1								5
	44						13					6
											22	7
	22											8
	12	33										9
	40	34										10
2		40									8.5	11
	27										6	12
	10									1		13
											27	14
					7	8.5					7	15
23							2.5		6			16
				9.5								17
18					4							18
2											6	19
			4									20
7					7				15			21
15												22
												23
									16			24
30												25
						13			26			26
									9			27
									20			28
												29
									5			30
									2			31
97	191	107	4	10.5	18	21.5	15.5	0	99	1	76.5	Monthly Total
												YEARLY
97	288	395	399	409.5	427.5	449	464.5	464.5	563.5	564.5	641	641



- 
- conditions for sowing were poor
 - heat and lack of moisture in the soil
 - minimal irrigation was applied
 - evaporation rates were high
 - soil organic carbon 2.25%

November 27, 2020

sowing inoculated seed



hot ($\sim 40\text{C}^\circ$), dry summer's day

compost extract application trouble shooting



tank-pump connection failed, only parts of field received compost extract

21/12/20

millet
(mostly weedy grass)

multispecies



21/12/20

millet crop (mostly
other grass took over)
potentially sown too
deep

multispecies



21/12/20

multispecies

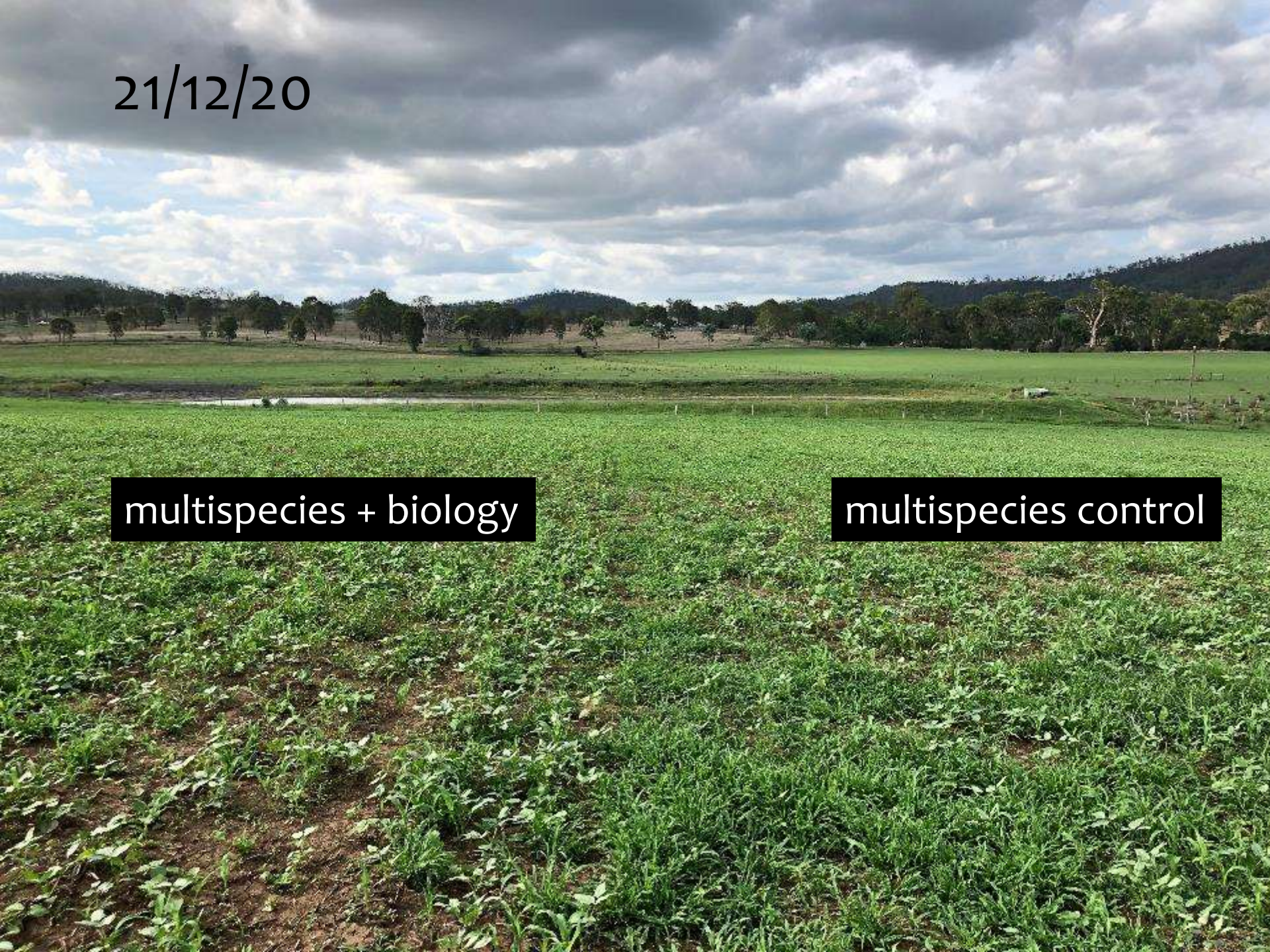
millet/grass



21/12/20

multispecies + biology

multispecies control









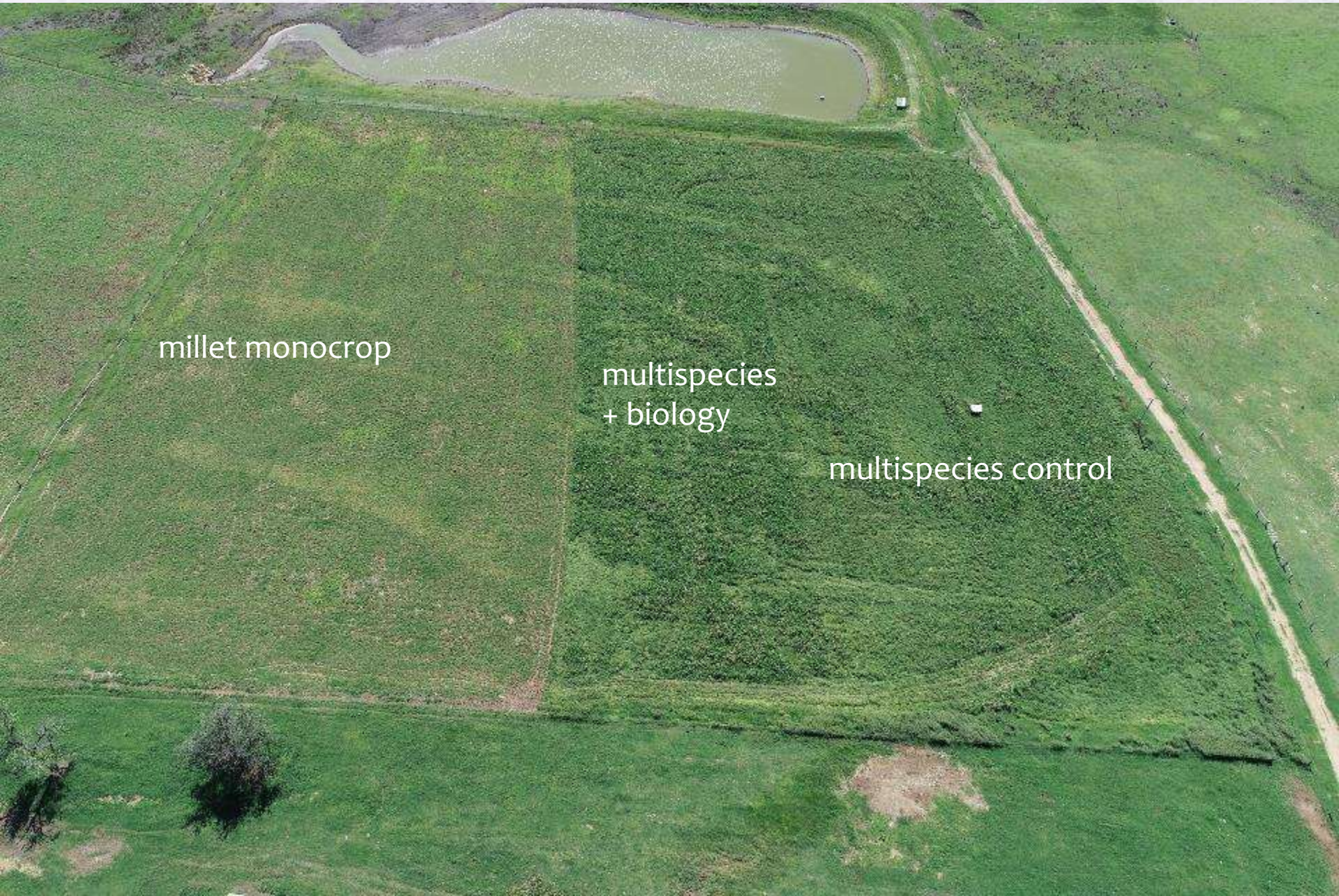




December 2020 – before rainfall



millet crop failed and was strip grazed



millet monocrop

multispecies
+ biology

multispecies control

a bit of rain in March got the crop growing


Rainfall Registration For Bolena 2021

From 8 am to 8 am daily

Date	January mm	February mm	March mm	April mm	May mm	June mm	July mm	August mm	September mm	October mm	November mm	December mm	Date
1	4.5				14								1
2			5										2
3						10							3
4			7.5	8									4
5	2.5			13	32								5
6	14			4									6
7				1									7
8		2											8
9	8.5		11.5			10							9
10			2										10
11					27								11
12					25								12
13		4											13
14			12		51								14
15			12										15
16		5	17										16
17	4.5	9	22										17
18													18
19													19
20													20
21			24										21
22			21.5										22
23													23
24			25										24
25		3											25
26													26
27													27
28	4.5												28
29													29
30													30
31													31
Monthly Total	34	23	159.5	26	149	20	0	0	0	0	0	0	Monthly Total
Running													YEARLY
411.5	34	57	216.5	242.5	391.5	411.5	411.5	411.5	411.5	411.5	411.5	411.5	411.5



April 2021 – multispecies cover-crop biomass measurements



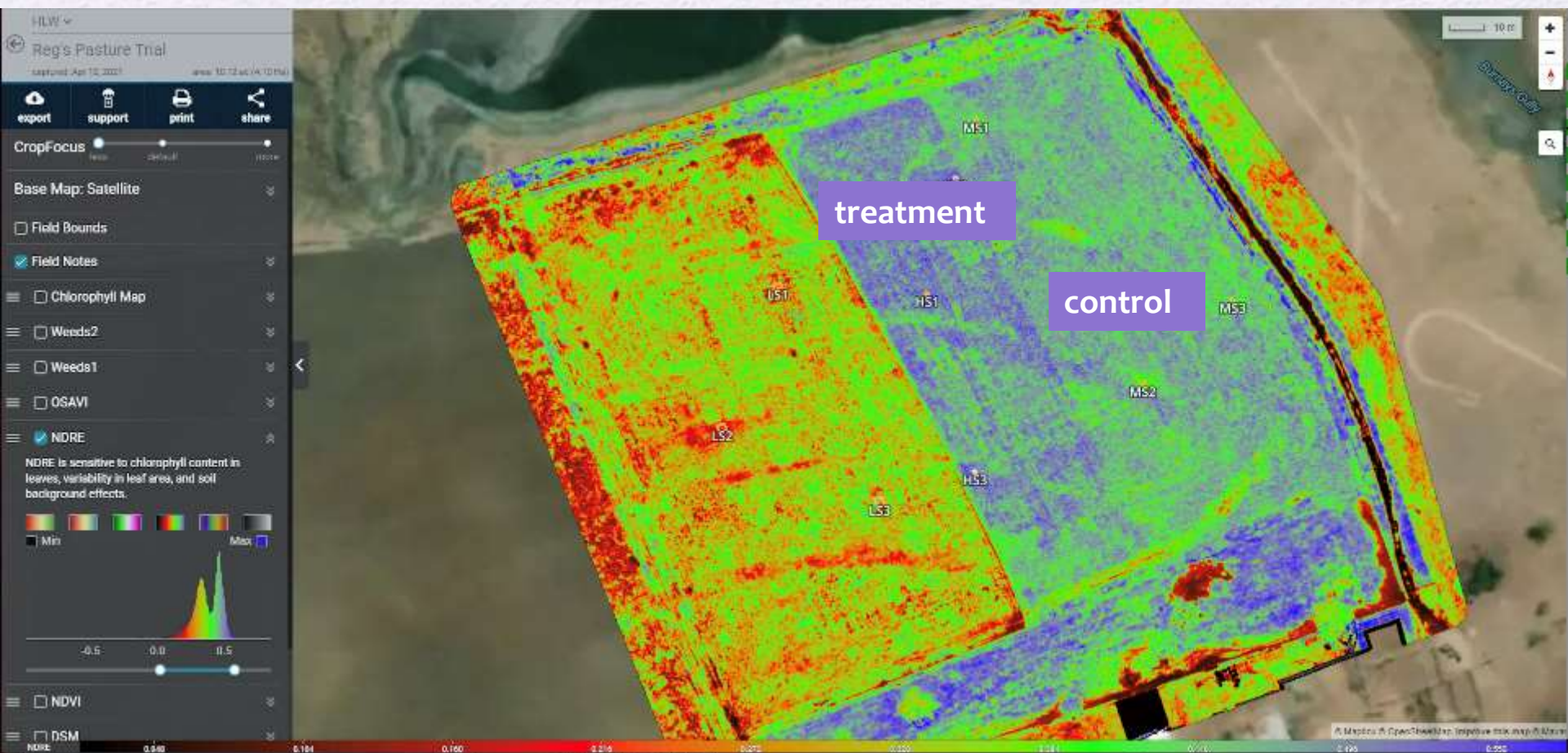
treatment plot 307g wet and 106 dry weight
control plot 227g wet and 88 dry weight

Normalised Difference Red Edge (NDRE) -

NDRE is sensitive to chlorophyll content in leaves, variability in leaf area for pasture assessment.

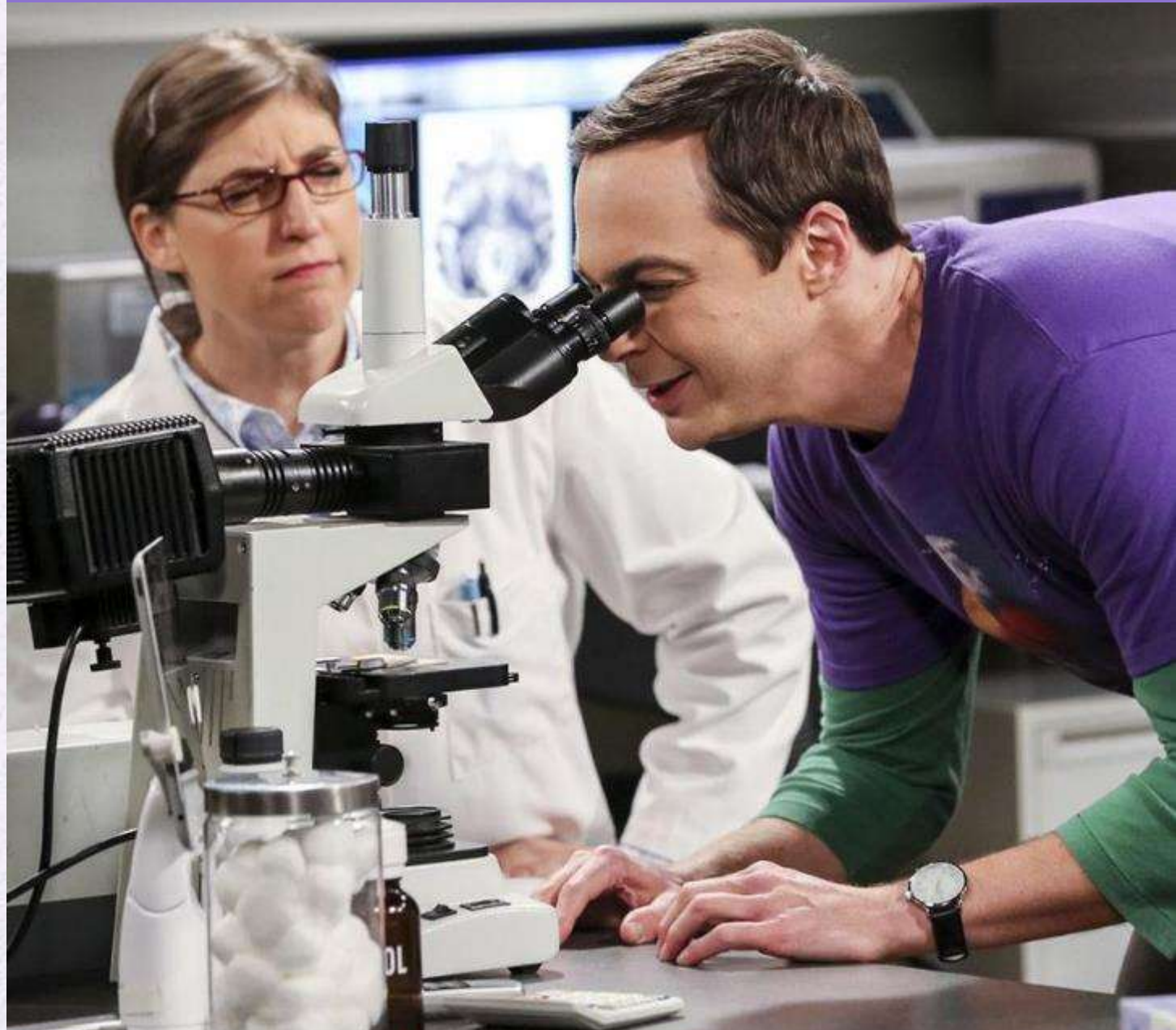
This is calculated using the red edge and near infrared bands, light reflectance humans cannot see

Treatment plot demonstrates higher chlorophyll content in multispectral capture data



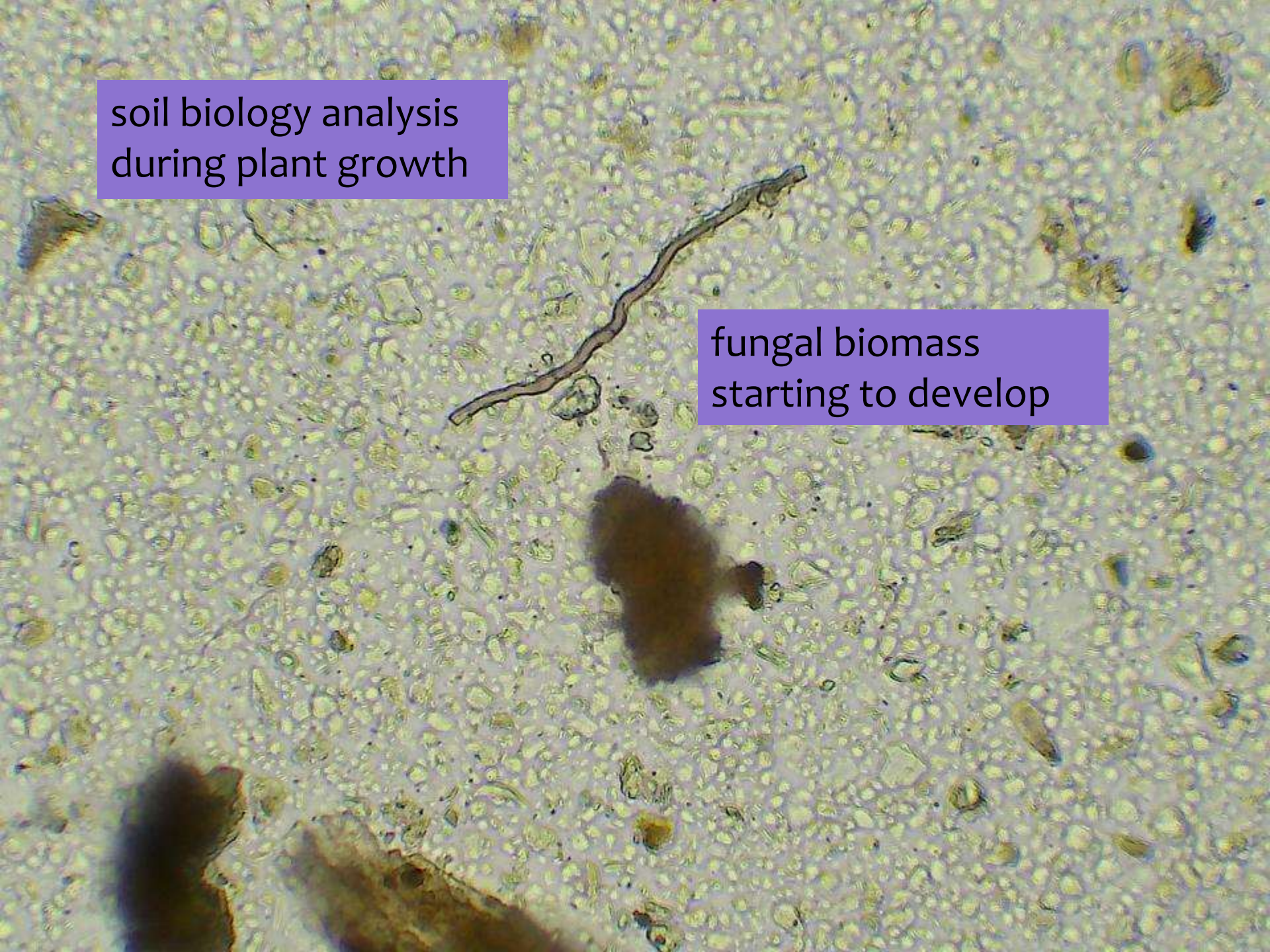
microscopy of soil microbiology

microscopy
analysis
continued as
crop
developed
and compost
matured



soil biology analysis
during plant growth

fungal biomass
starting to develop



A microscopic view of soil showing various particles and structures. The background is a light-colored, granular matrix. There are several dark, irregularly shaped clumps of organic matter scattered throughout. A prominent, dark, thick, and slightly curved structure, identified as a beneficial fungal hypha, is visible in the center-left area. Other smaller, dark, circular or oval structures are also present.

organic matter

beneficial fungal
hypha, dark and thick

A microscopic image showing a single, long, thin, and slightly curved fungal hypha. The hypha is light brown or tan in color and has a distinct, darker, rounded structure at one end. The background is a light, textured surface with numerous small, circular, and irregularly shaped particles, likely plant debris or soil components, scattered throughout.

fungus hypha

beneficial fungus hyphae extract nutrients from tough plant debris, released when hyphae are consumed by nematodes and arthropods, in plant available form

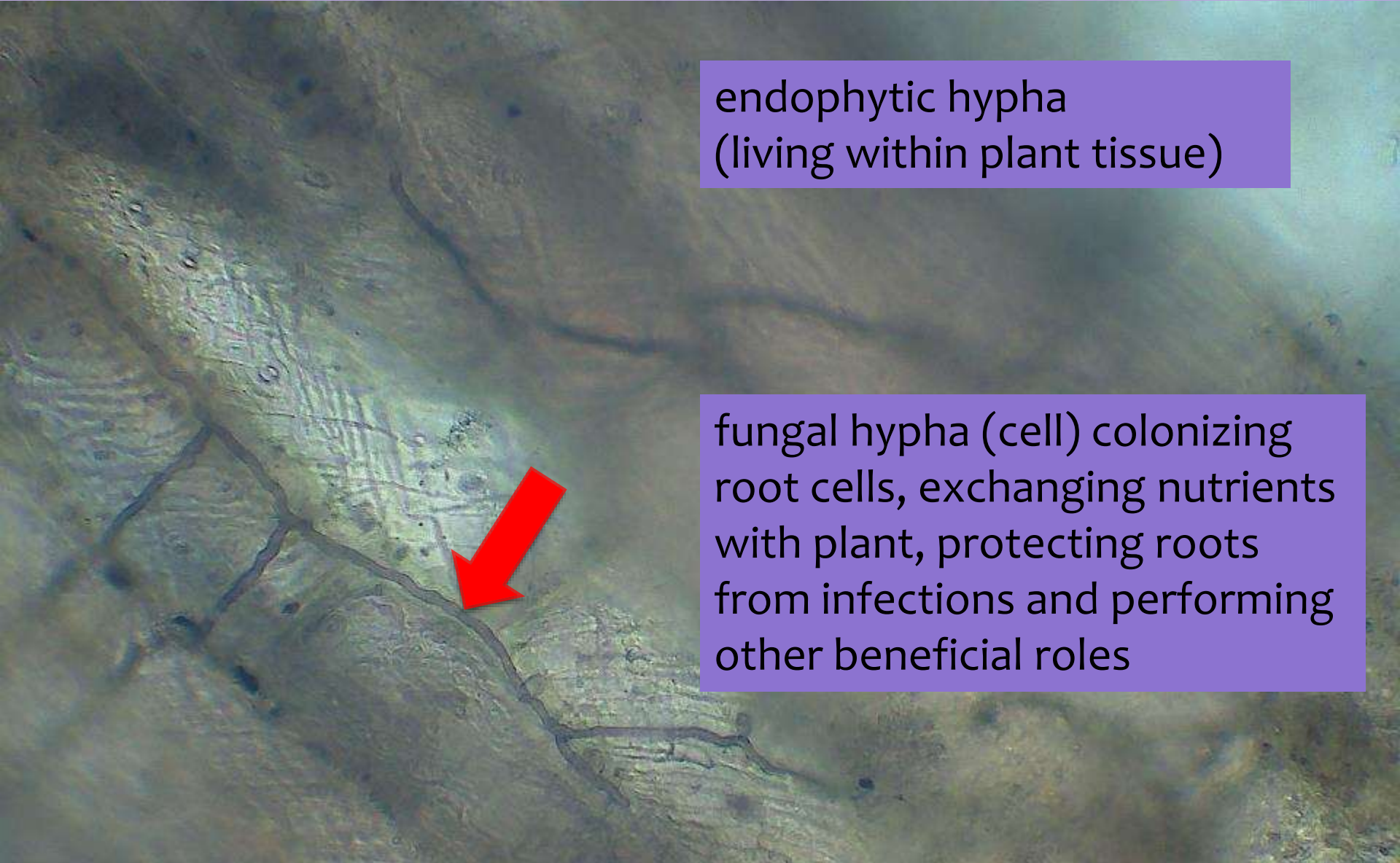
A microscopic image showing a long, thin, brownish fungal hypha extending diagonally across the frame. The background is filled with numerous small, irregular, light-colored particles, likely soil components or other microorganisms. The hypha has a slightly textured, fibrous appearance.

fungus hypha

when beneficial fungus hyphae die, containing chitin, fulvic and humic acids which are recalcitrant humus building blocks, they build soil carbon and soil structure

roots and rhizosphere microscopy analysis

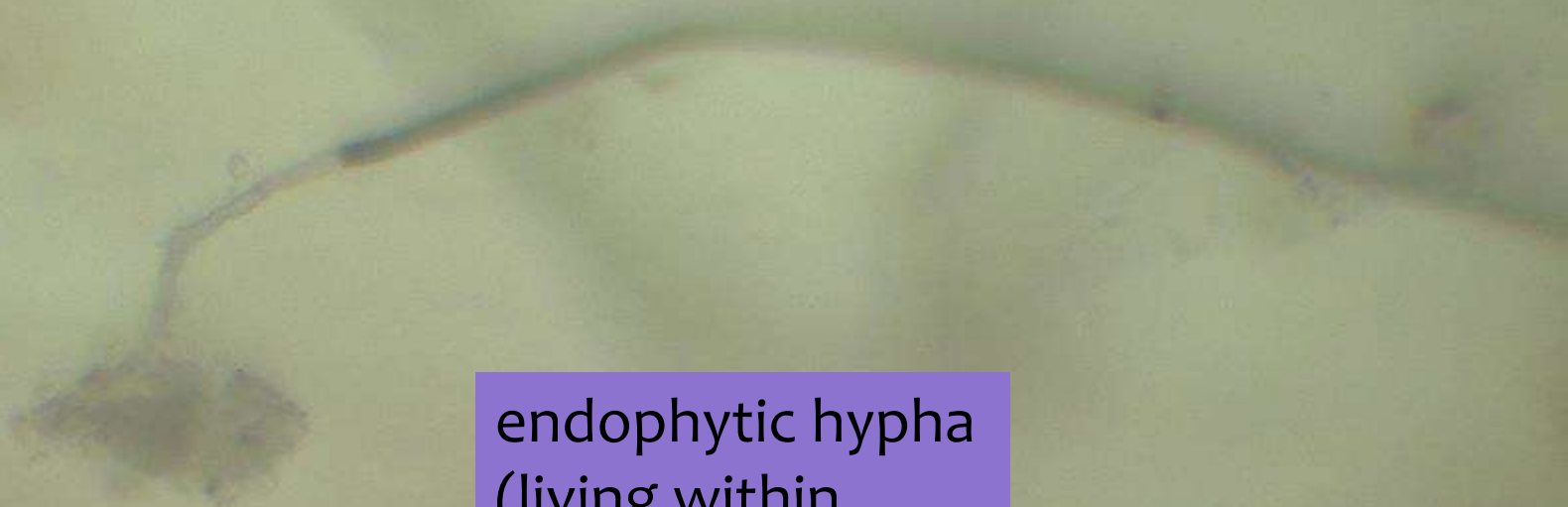
sorghum root associated fungi

A light micrograph showing a cross-section of sorghum root tissue. The image displays several large, polygonal plant cells with thick, dark cell walls. Within these plant cells, there are numerous thin, dark, branching structures representing fungal hyphae. A prominent red arrow points to one of these hyphae, highlighting its presence inside the plant tissue.

endophytic hypha
(living within plant tissue)

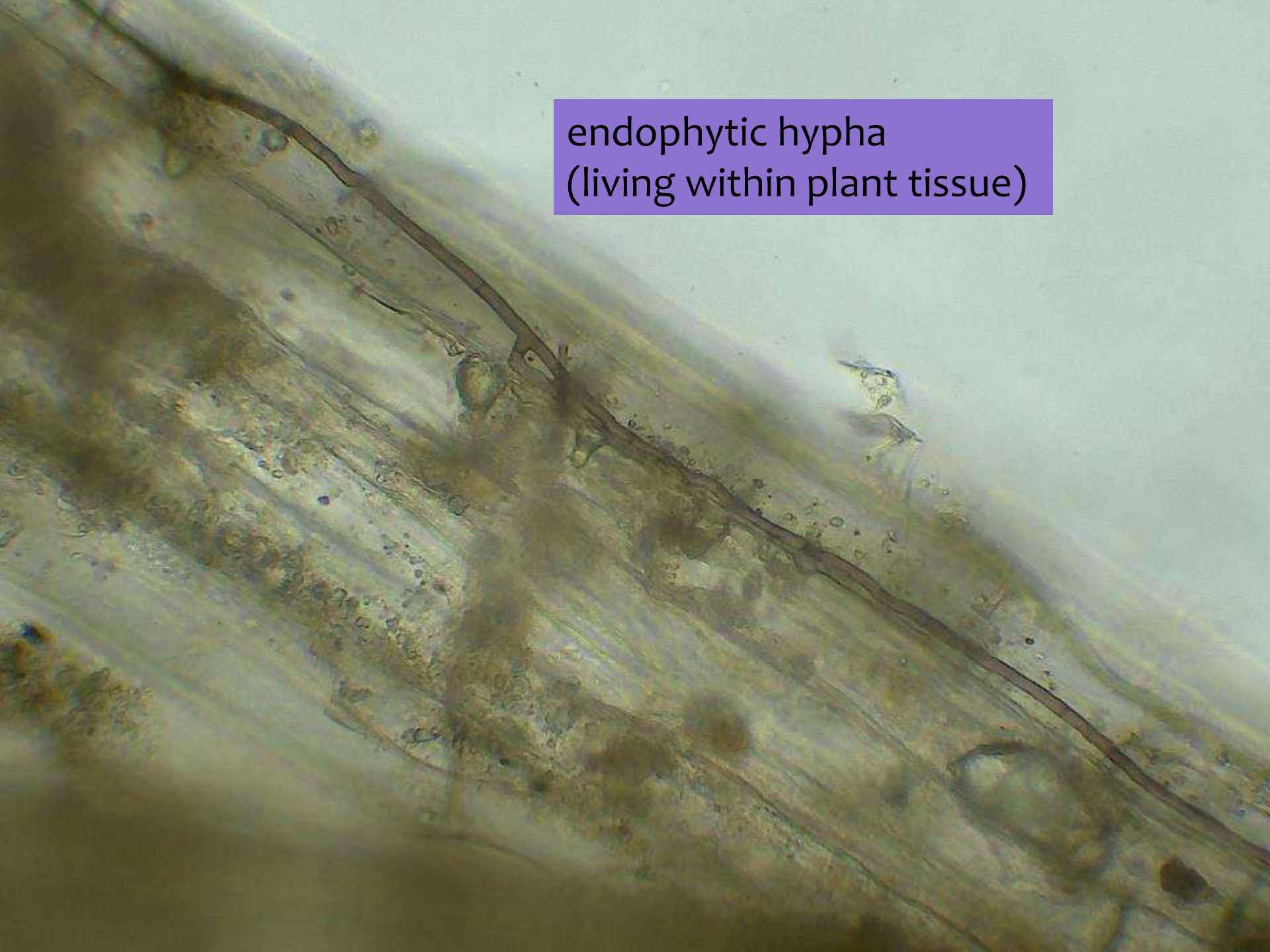
fungal hypha (cell) colonizing
root cells, exchanging nutrients
with plant, protecting roots
from infections and performing
other beneficial roles

beneficial hypha infection within sorghum root



endophytic hypha
(living within
plant tissue)

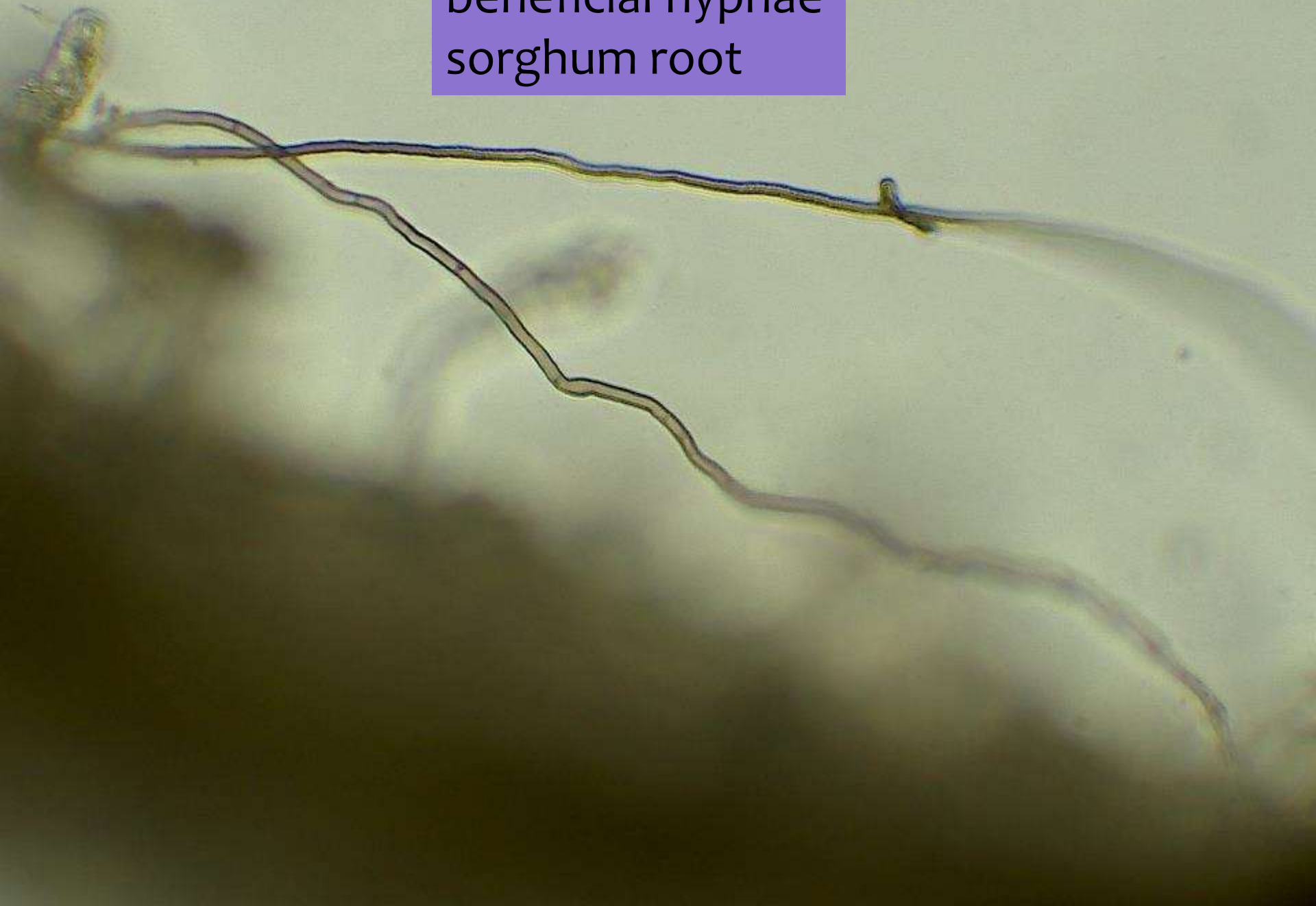
endophytic hypha
(living within plant tissue)



endophytic hypha branching (living within plant tissue)



beneficial hyphae
sorghum root



A microscopic image showing a long, thin, wavy hypha. The hypha is light brown or tan in color and has a slightly irregular, beaded appearance. It is positioned horizontally across the upper half of the frame. The background is a light, off-white or pale yellow color, with some small, dark, irregular particles scattered throughout. A purple rectangular box is overlaid on the image, containing the text "beneficial hypha sorghum root".

beneficial hypha
sorghum root



fungal feeding nematode, releases plant available nutrients like ammonium, selecting against weed proliferation, as weeds prefer nitrate



arcella, protozoan: consume bacteria in large amounts, releasing plant available nutrients

Rhizobium nodule on cowpea roots

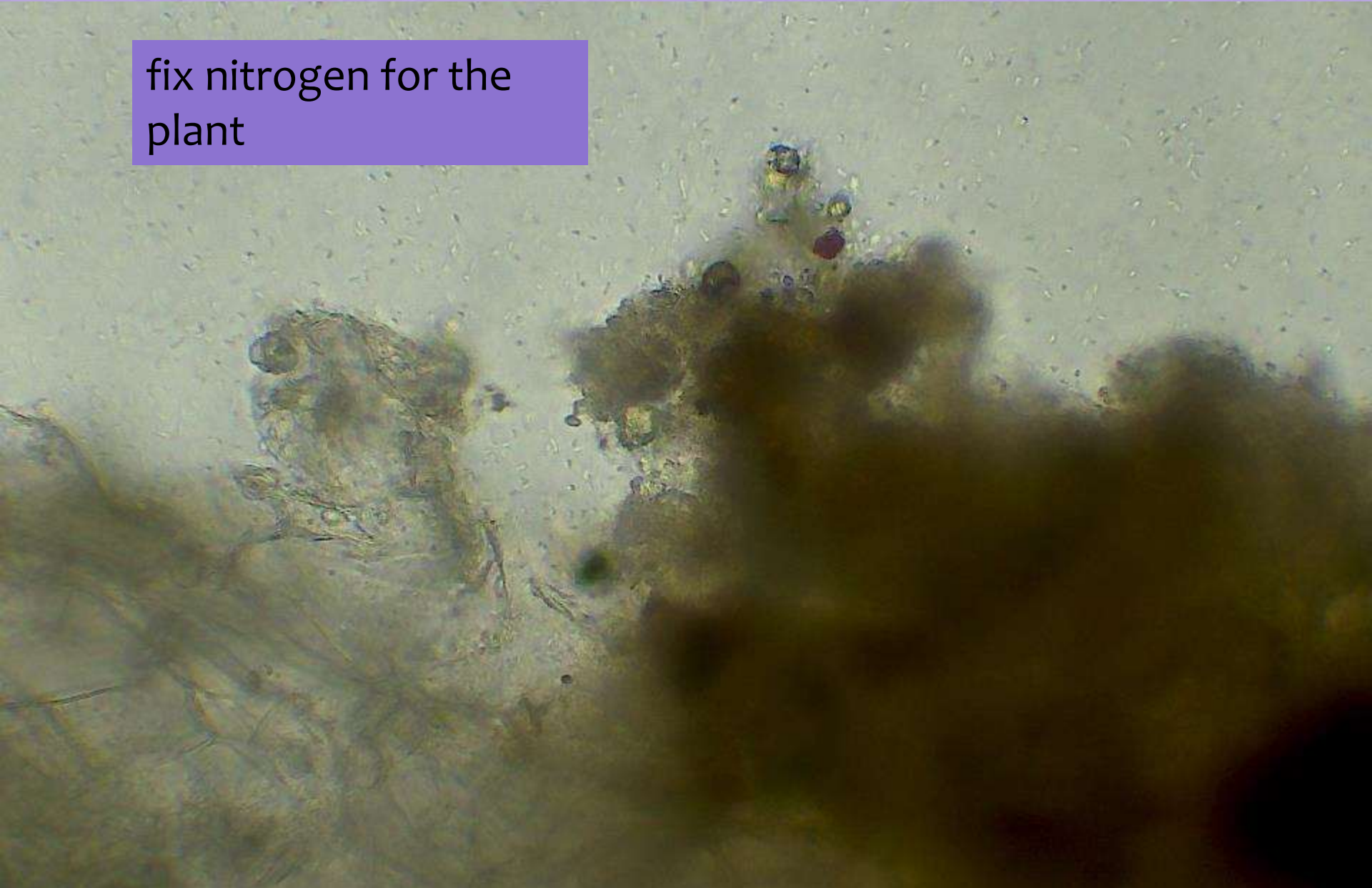




Rhizobium nodules fix nitrogen in legumes

Rhizobium bacteria (rods) from squashed nodule

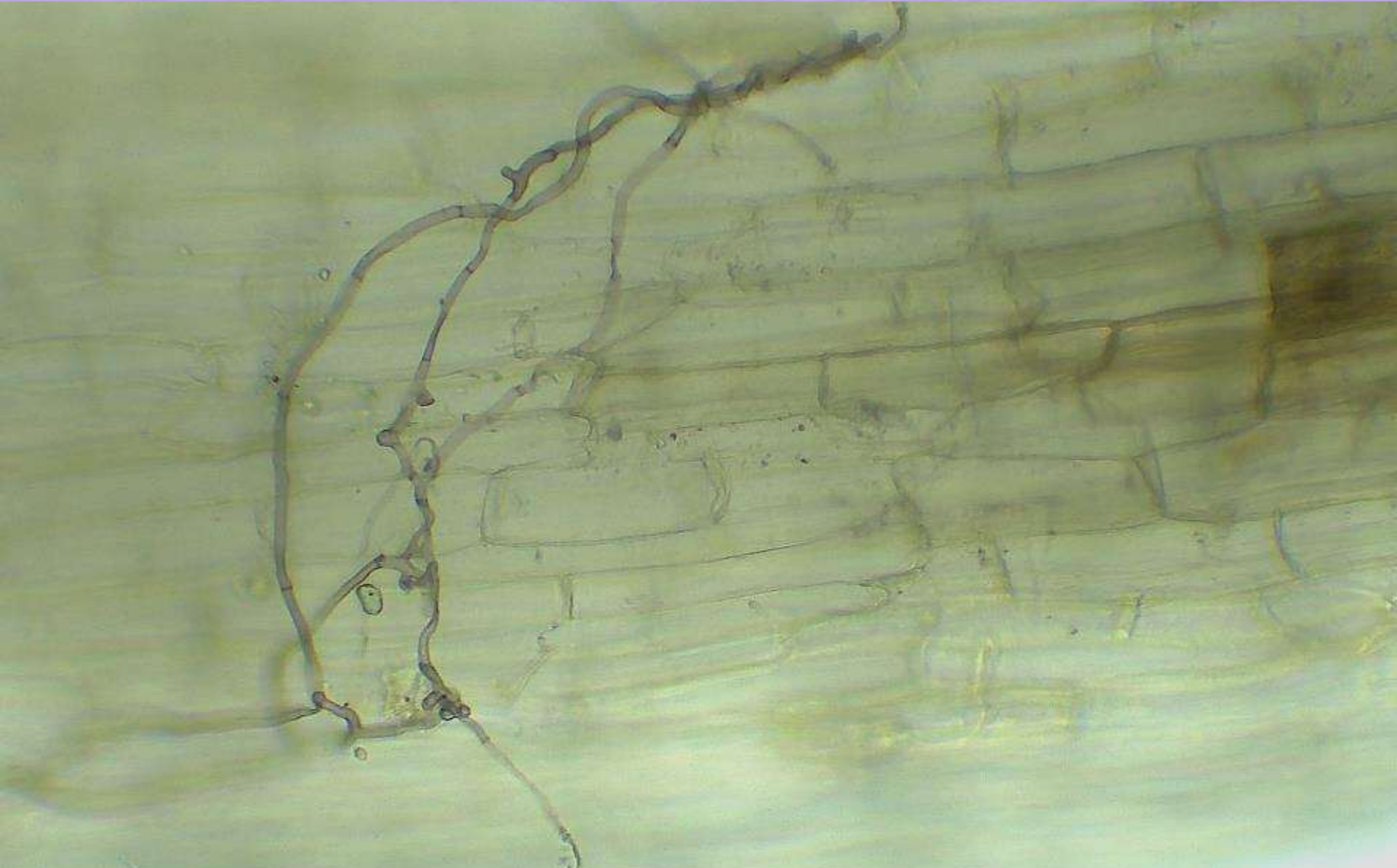
fix nitrogen for the
plant



fungus hypha in cowpea root



branching fungal hyphae within cowpea root



fungus hypha from cowpea rhizosphere



fungus hypha, thick and dark is what we want



May 2021 – crimper-roller trial



5th of May open field day



~40 members of the community attended an open field day to learn about the trial



presentation on the trial and the role of beneficial soil microbe cultivation for improved plant nutrition, immunity and soil health

AirBORN presented on the use of multispectral capture in plant health assessment



direct drill demo





cowpea and sorghum thriving





goals

diversity of plant families :
diverse exudates improve
nutrient cycling and plant
immunity

minimise/avoid soil
disturbance: direct drill
to ensure survival of
microbes

provide perennial
ground cover to feed
beneficial microbes

increase:
soil moisture, structure
drought resistance,
carbon sequestration,
nutrient availability/cycling,
plant immunity/vigour,
animal/human nutrition

eliminate weeds,
fertilizer and
pesticide costs,
reduce work-load

ensure soil moisture

create compost

check for microbial
diversity and apply
extract/tea to
soil/plants

retain crop residue and
mulch to increase soil
organic matter and
fungal biomass

Giving Soil

<https://www.patreon.com/givingsoil>



- Community cultivated soil microbiome
- Given to producers
- Applied to land dedicated to biological restoration
- Food tested for nutritional value and sold at a premium

- Chemical free
- Restorative and regenerative
- No till
- Perennial cover cropping



flow through worm farm







Johnson-Su Bioreactor

Dr. David C. Johnson, molecular biologist and research scientist at the University of New Mexico, has developed a system that brings lifeless soils back to life by reintroducing beneficial microorganisms to the soil with biologically enhanced compost.









For more info contact:
Sandra Tuszynska
loveoursoils@gmail.com
0459 228 575

services:

- soil microscopy
- consultancy
- worm farm and compost set up and analyses
- community education
- <https://www.patreon.com/givingsoil>



Thank you