Transition to SOIL HEALTH

Lets make a move!

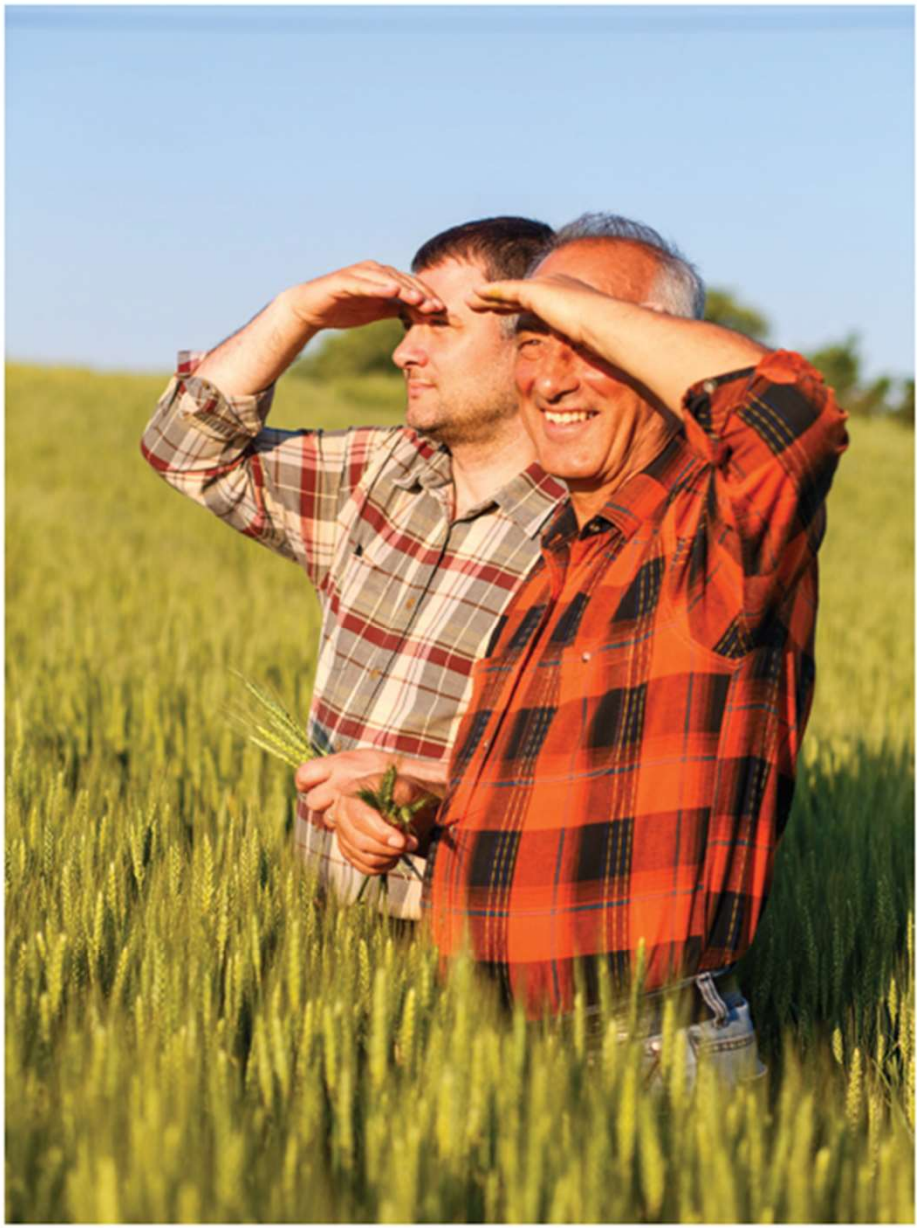
A framework to help put soil management learnings into practice to achieve measurable benefits

Transition to SOIL HEALTH

Let's make a move

Put soil health knowledge into practice

Transition To Soil Health equips growers to understand all the aspects of soil health, identify the key constraints particular to their situation, implement a practical action plan for improvement, and measure the outcomes to assist ongoing practical change.



Transition to SOIL HEALTH

Properties of a healthy soil

- Deep root zone
- Resilient and stable structure
- Favourable strength & aeration
- High water infiltration rate
- High moisture storage capacity
- Adequate internal drainage
- Balanced stores of nutrients
- Low levels of pathogens
- High soil organic matter
- High bio-activity & diversity
- Low levels of toxic substances
- Protected surface & low erosion
- Favourable pH
- Favourable temperature

From Slavich 2001 and Stirling *et al.* 2016

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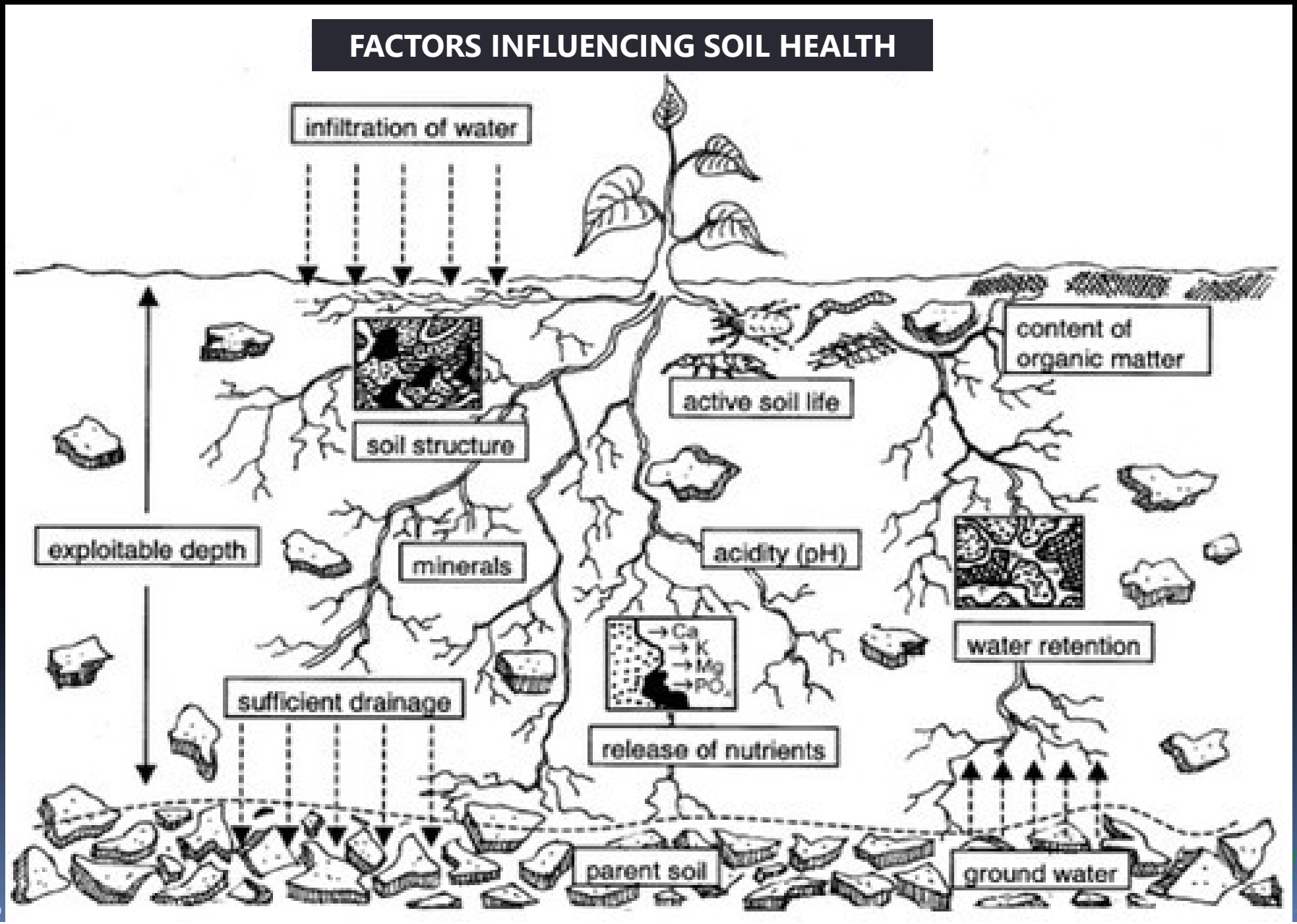
Transition to
SOIL HEALTH

FACTORS INFLUENCING SOIL HEALTH



Transition to SOIL HEALTH

The 'BIG 4' soil processes

- Each soil health **property** is the result of **four main soil processes**
  - Residue digestion
  - Nutrient cycling
  - Soil structure maintenance
  - Pest & disease regulation

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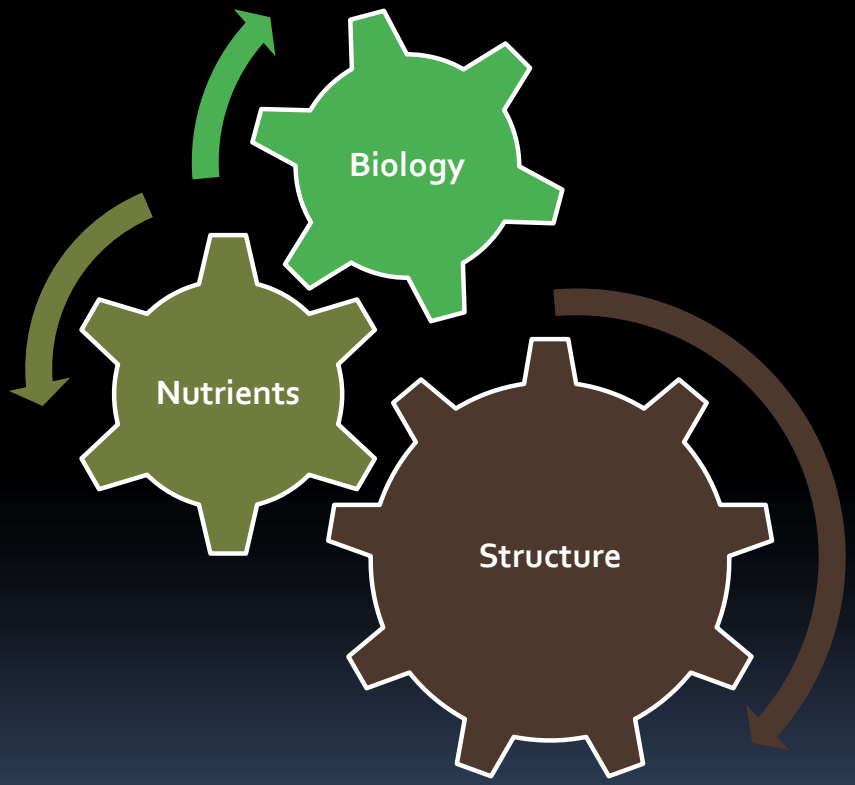
Transition to SOIL HEALTH

Principal interactions

Soil components



Soil processes

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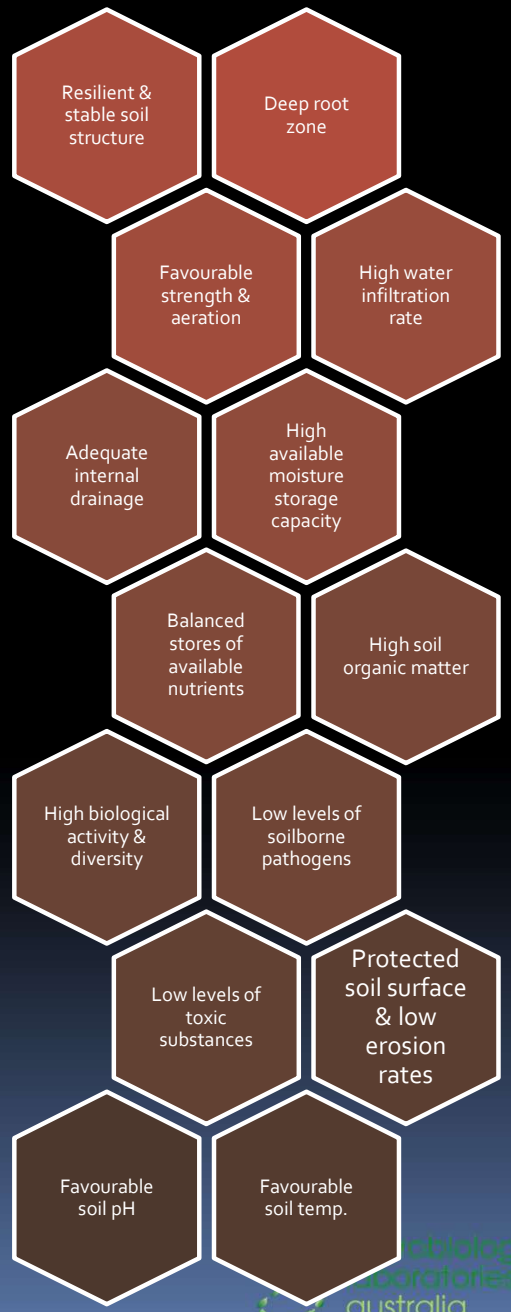
Soil properties



Transition to SOIL HEALTH

Principal interactions

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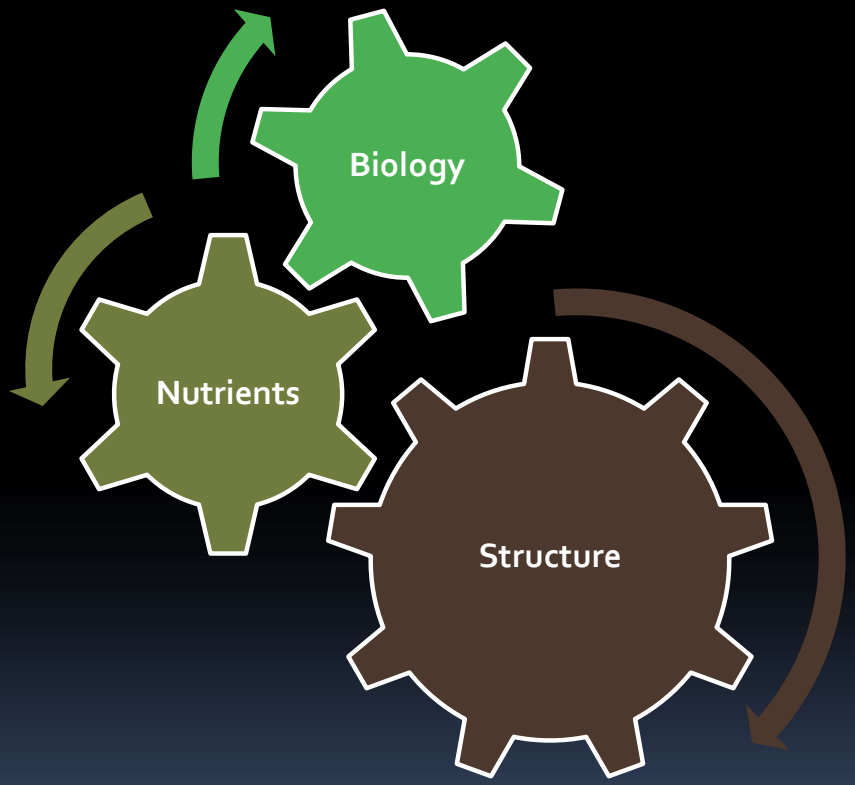

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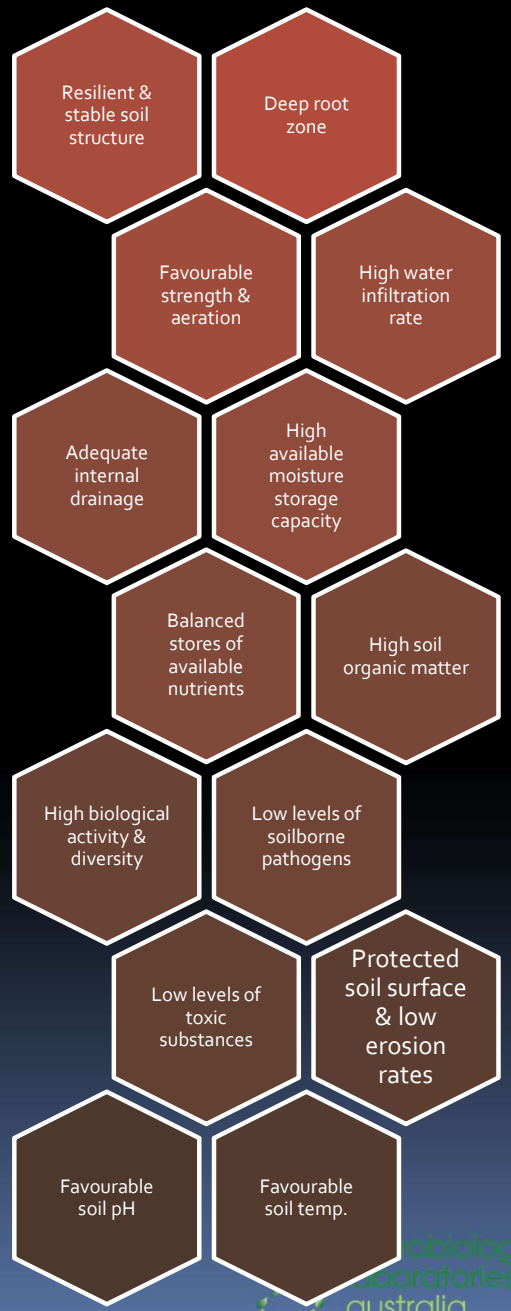

Transition to SOIL HEALTH

Principal interactions

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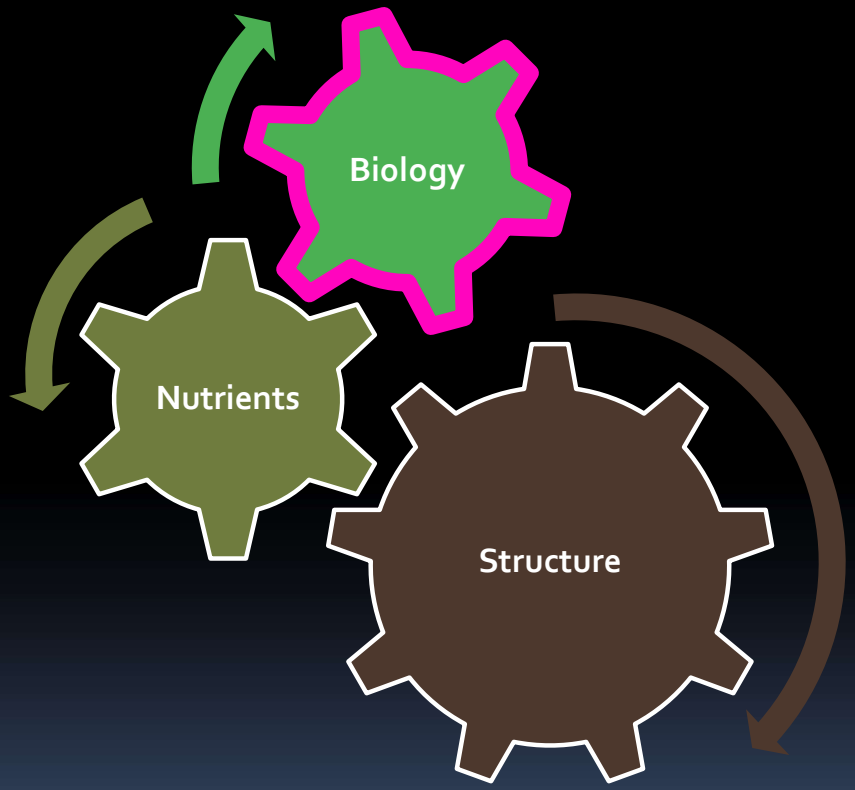

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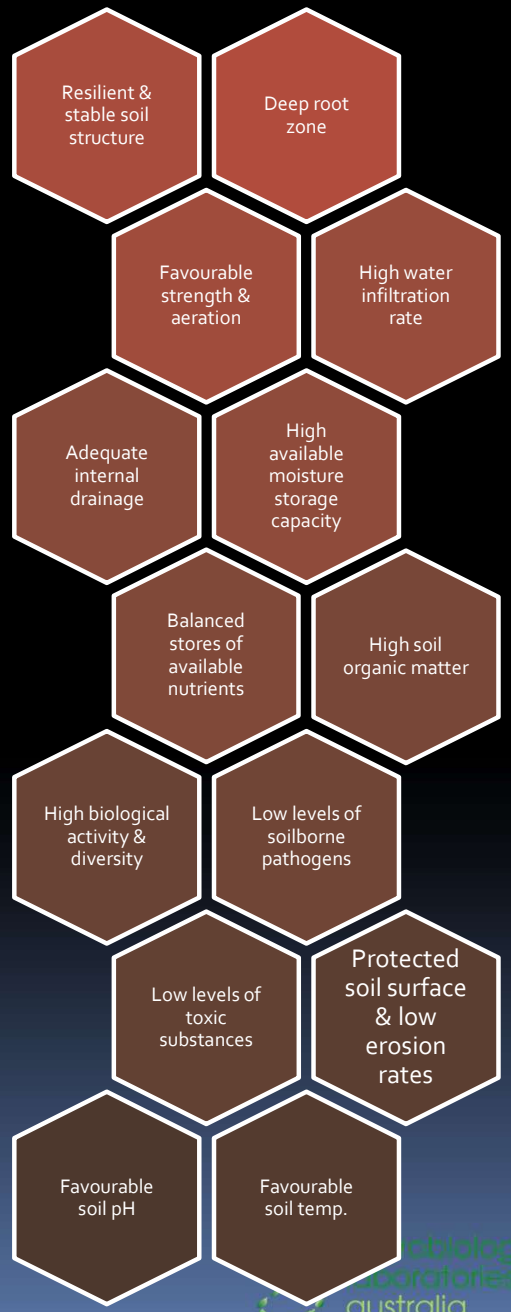

Transition to SOIL HEALTH

Soil Processes, Life & Health

Soil Processes ≈ Soil Life ≈ Soil Health

‘health’ needs ‘life’

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Transition to SOIL HEALTH

Exploring life in the soil

Biology

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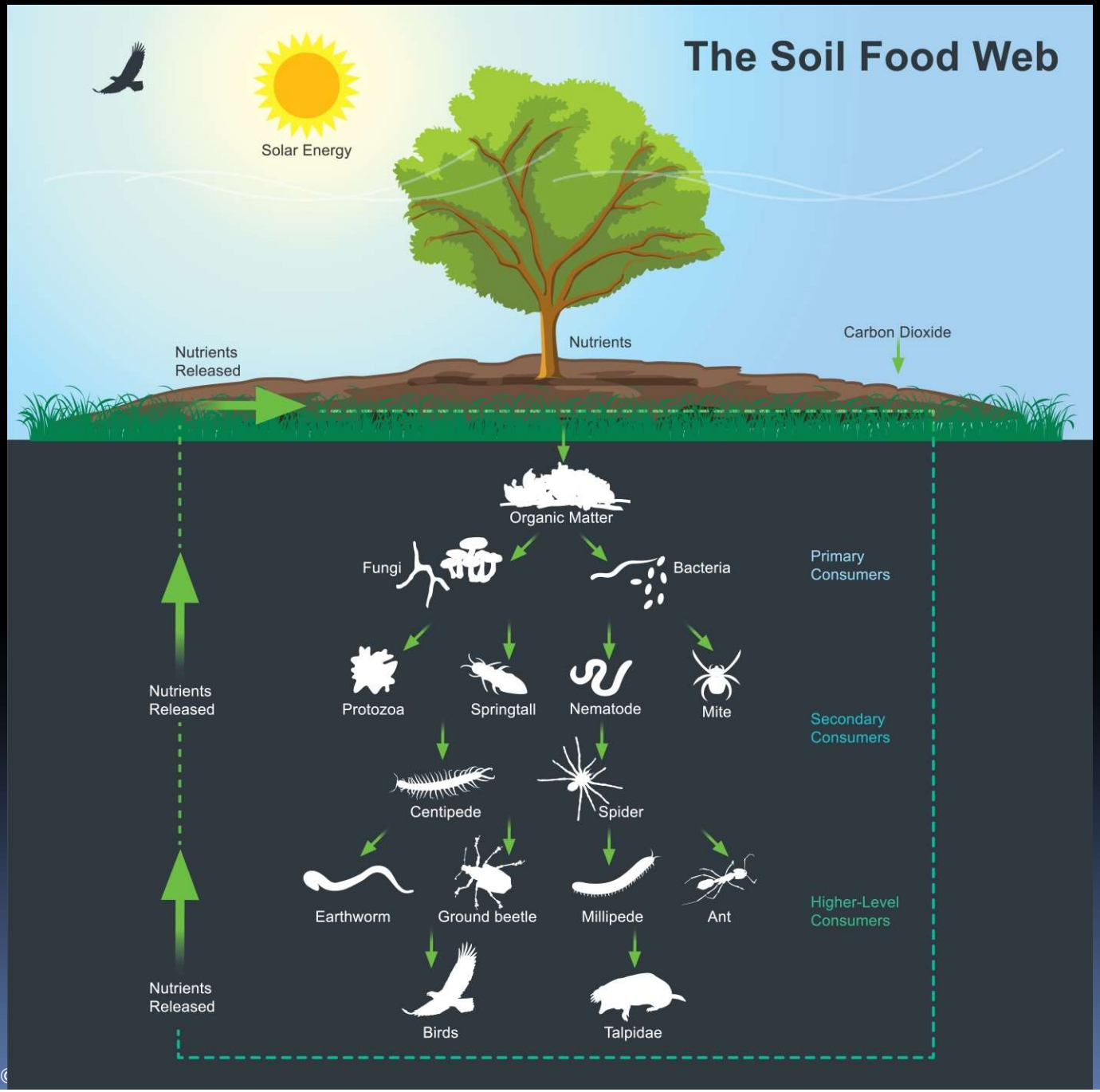
Transition to SOIL HEALTH

Soil Biology – The Soil Food Web



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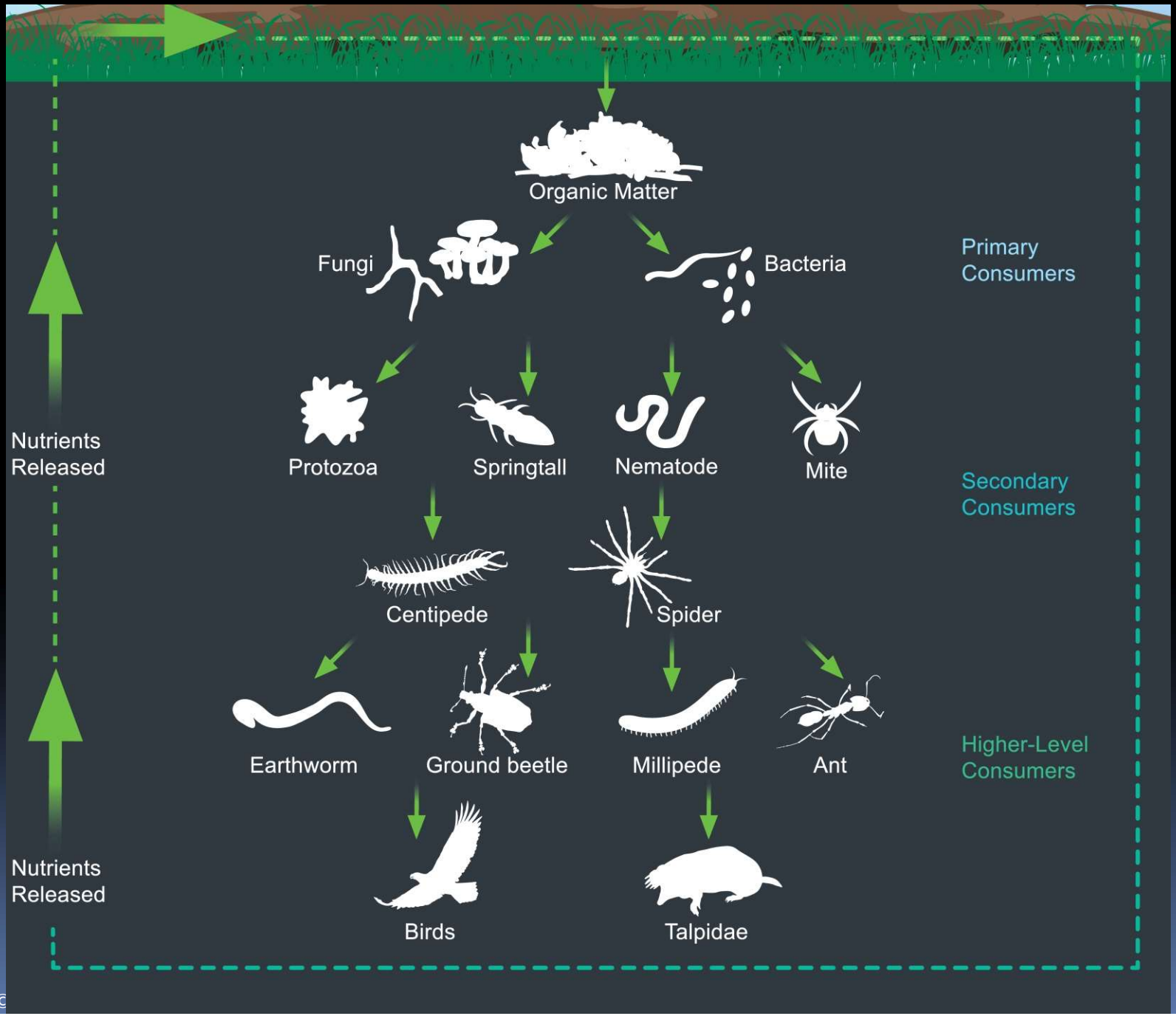
Soil Biology – The Soil Food Web



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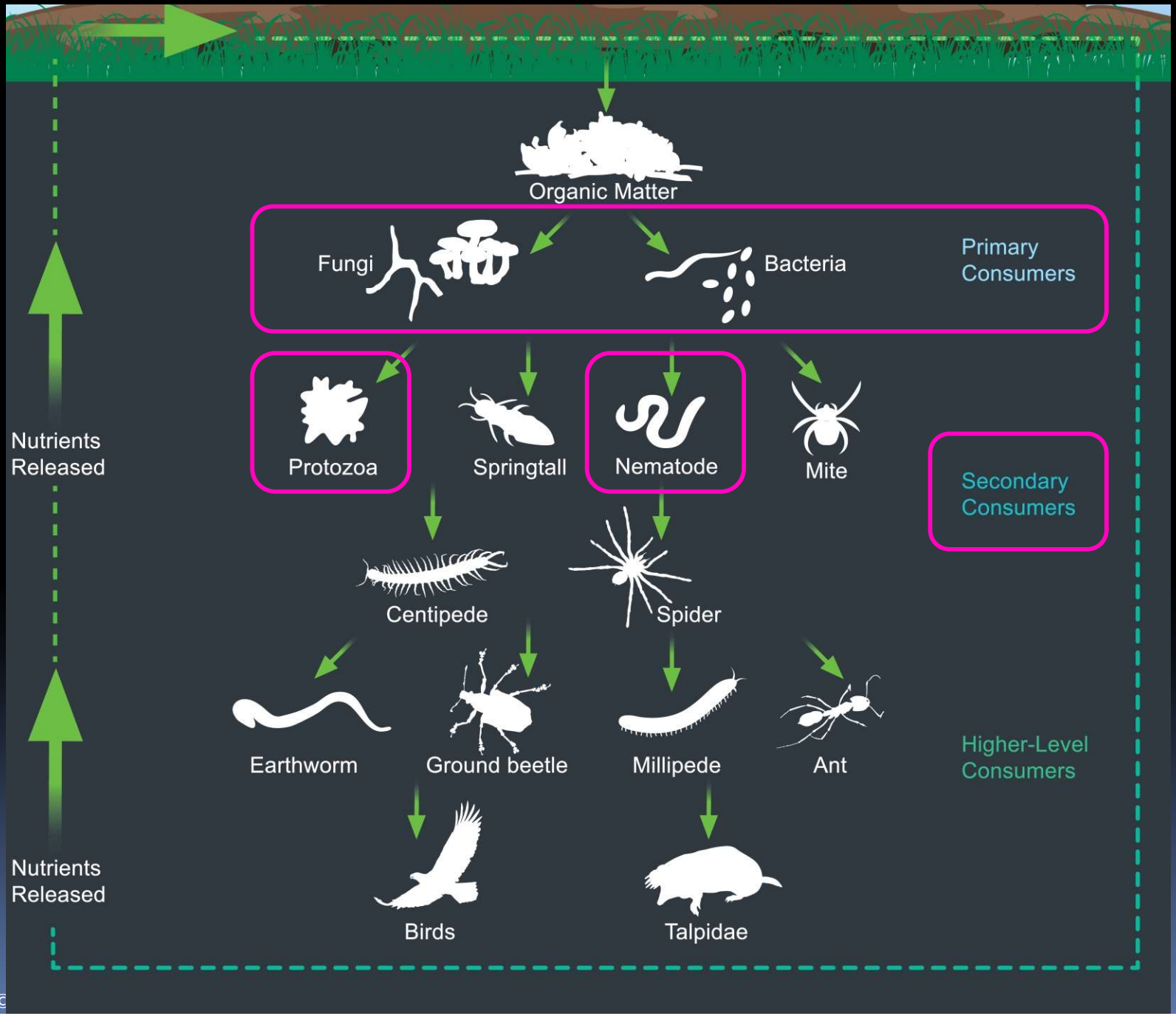

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Soil microbiology – What is it?

- Organisms that are too small to see with the naked eye
  - Prokaryotes
    - Bacteria *
    - Archaea
  - Eukaryotes
    - Fungi *
    - Protists
      - Protozoa →
      - Algae *
    - Nematodes

Complexity

* Some colony-forming or multi-cellular organisms can be seen with the naked eye. E.g., actinobacteria/mycetes, filamentous fungi, algal blooms.

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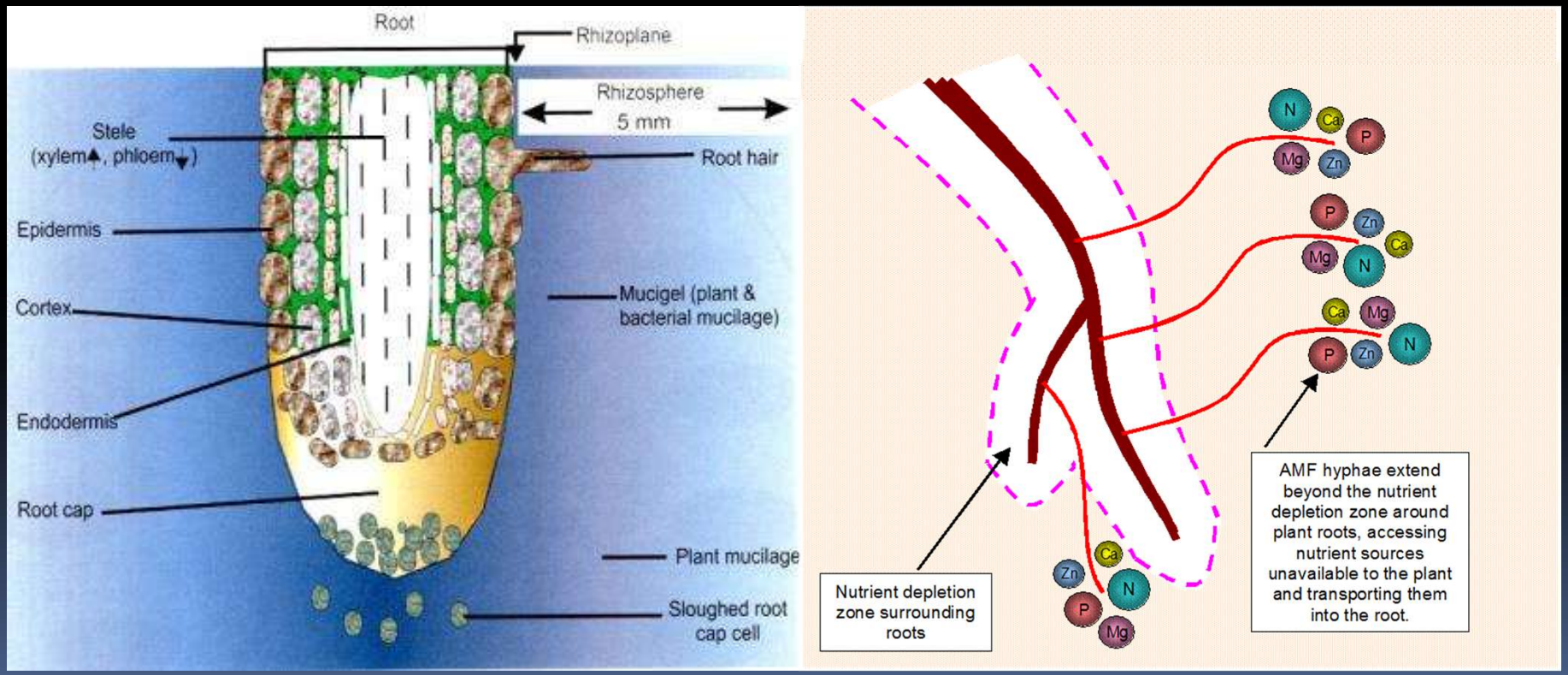
Soil microbiology – Where is it?

- Everywhere, but
- Most prevalent in the rhizosphere



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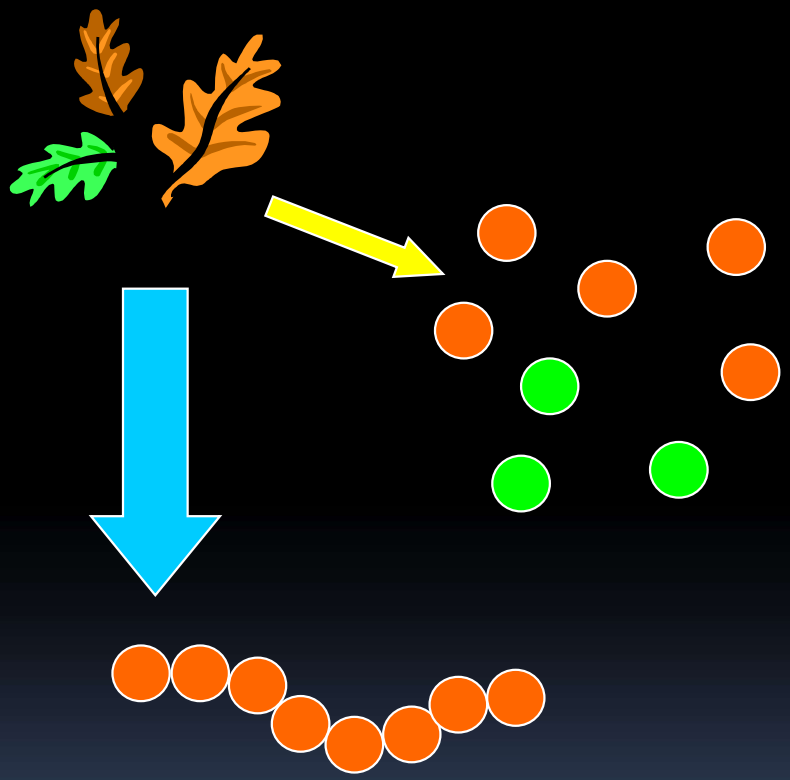
Soil Microbiology – How it works?

Uptake of molecules into microorganisms



Small molecules
e.g. sugars, amino acids

Pass through the membrane

Large molecules
e.g. cellulose, starch

too big to pass through membrane

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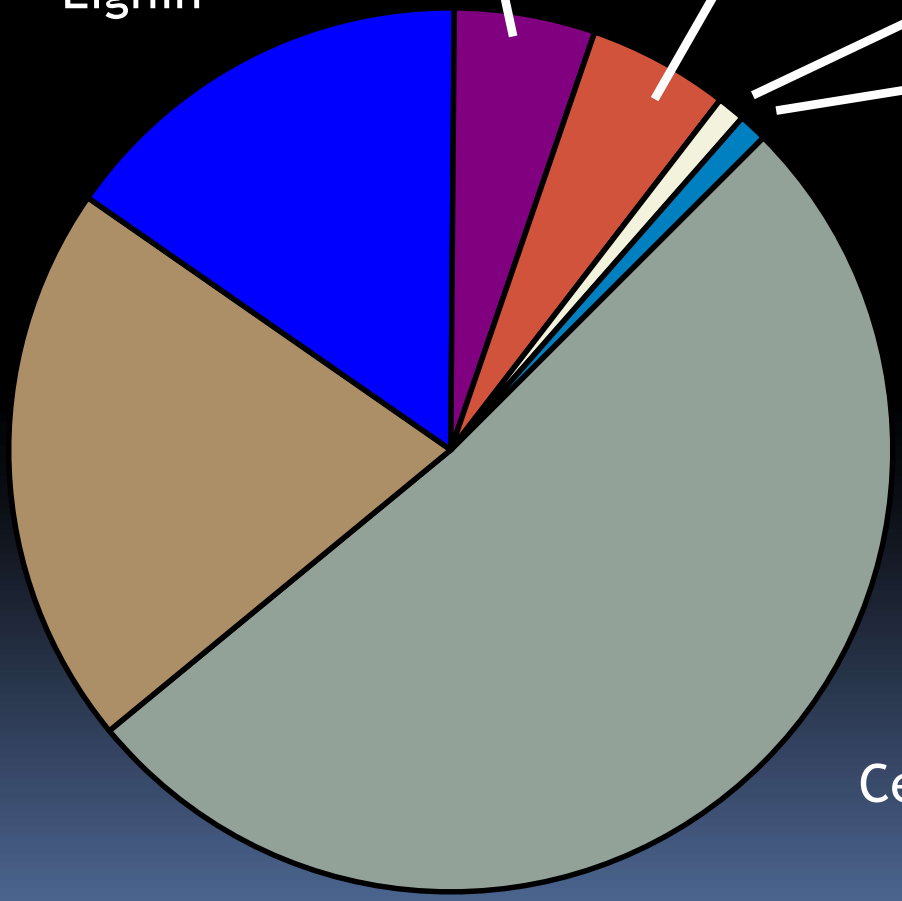
Plant residues – Microbe food



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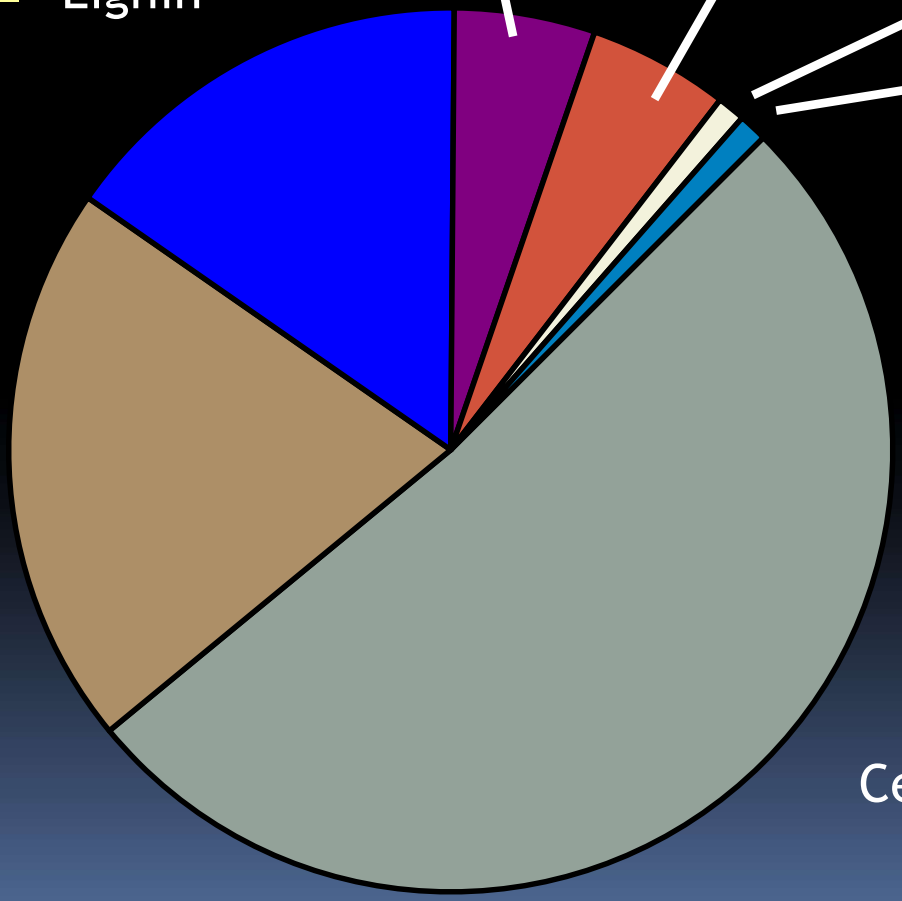

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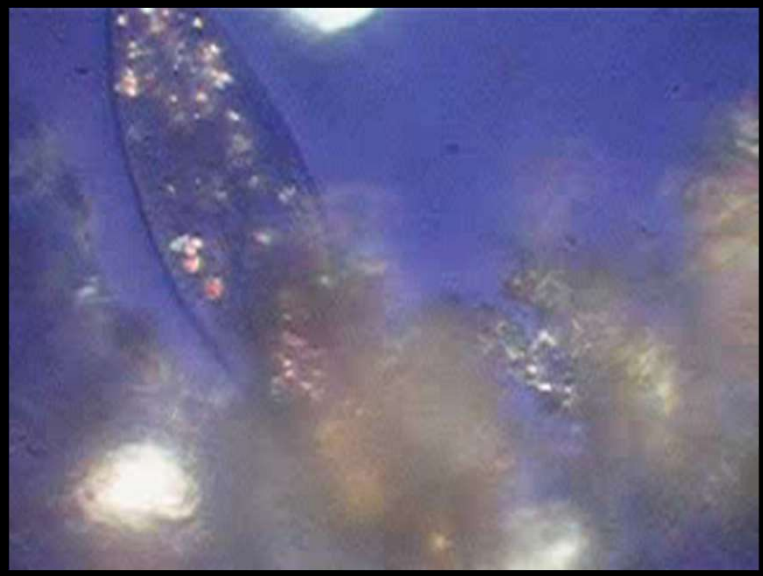
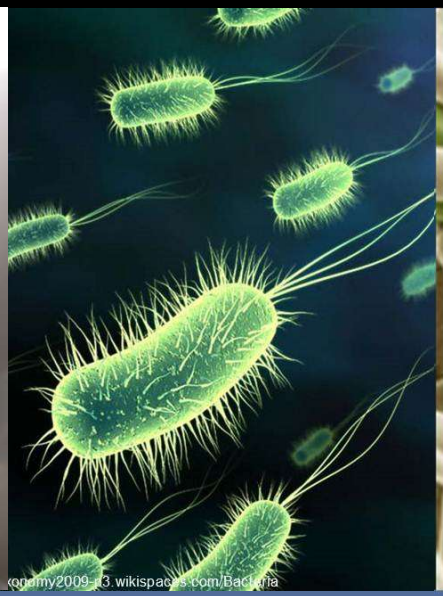
Types of soil microbes

- Bacteria
- Archaea
- Fungi
- Other microbes
  (e.g. protozoa, nematodes, viruses)





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Soil microbiology - Diversity

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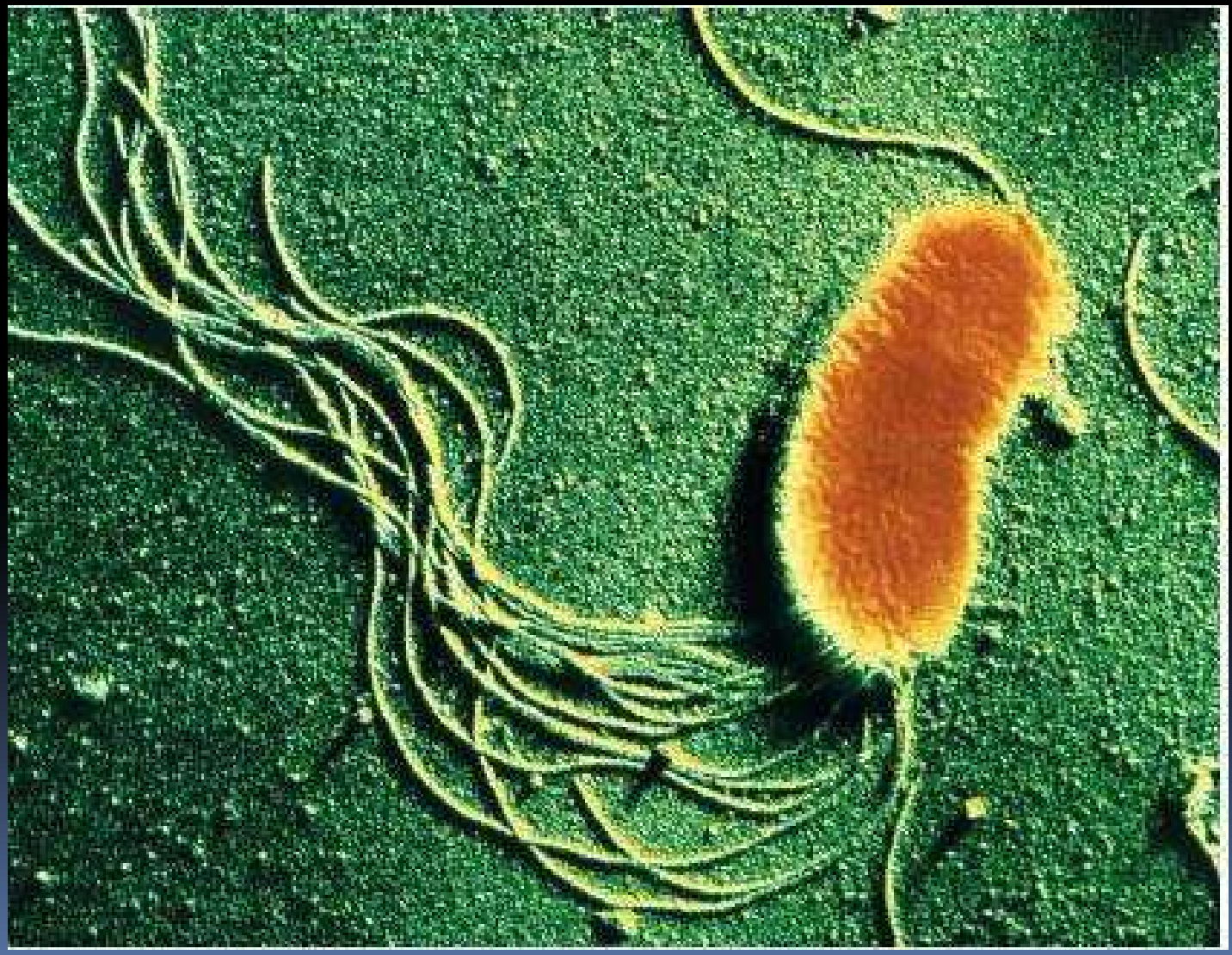
Soil bacteria - Example

- *Pseudomonas fluorescens* (P-solubilising)



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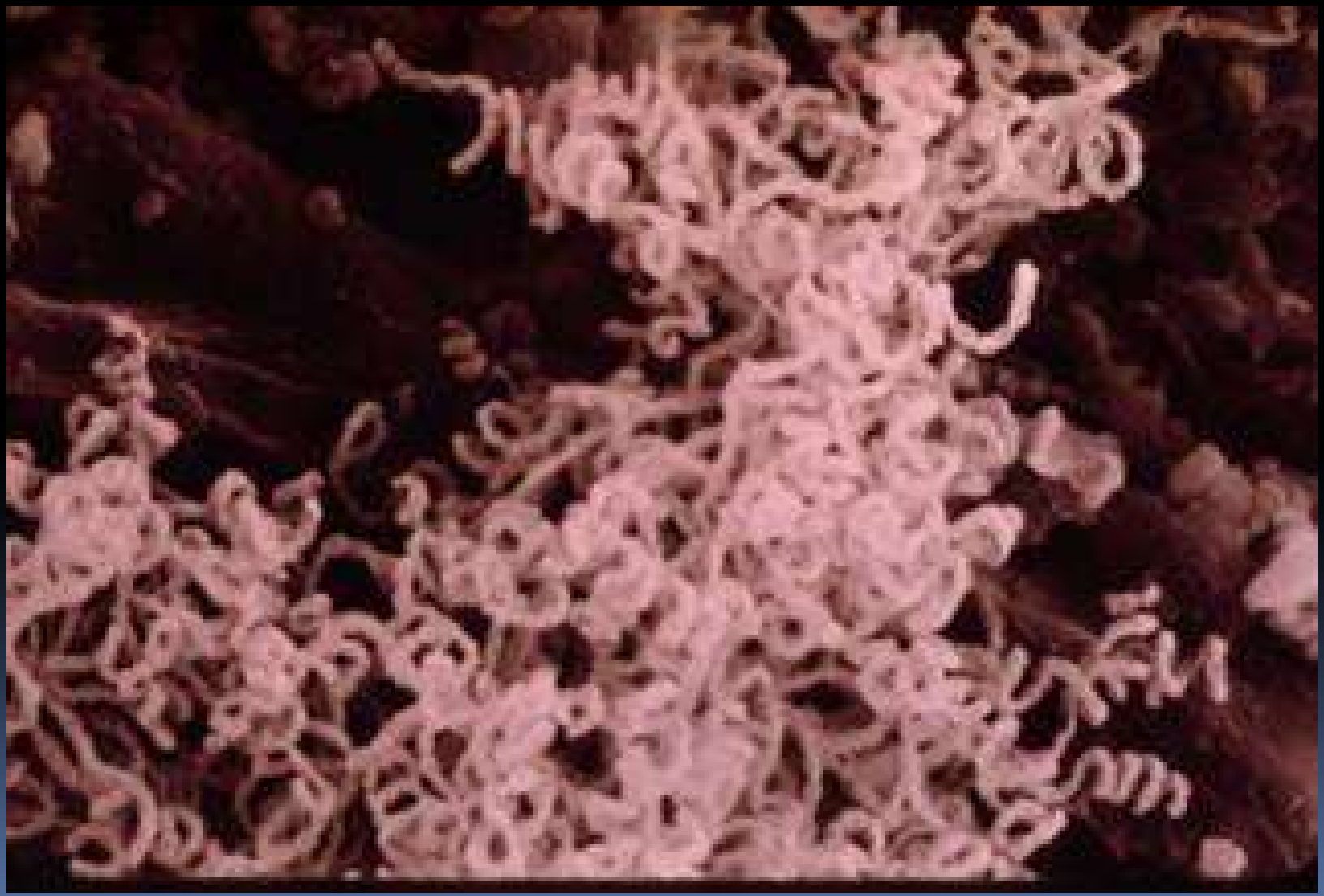
Soil bacteria - Example

- *Actinomycetes* (break down organic matter)



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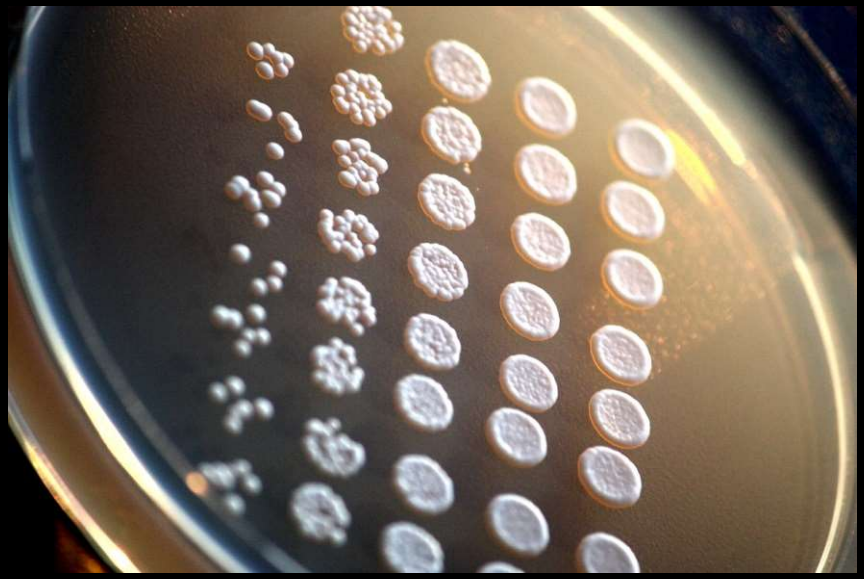
Soil fungi - Example

- Yeasts



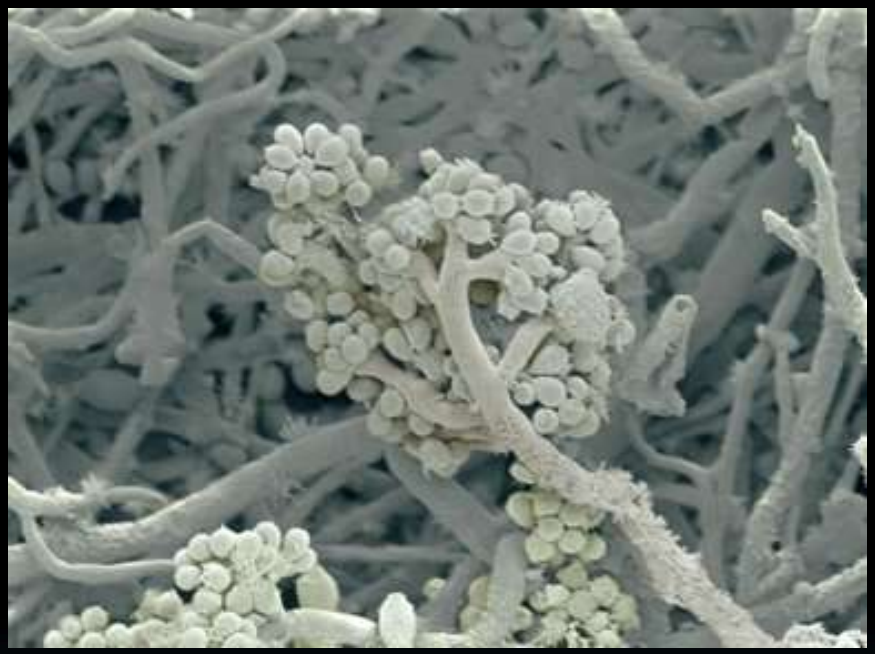
↑ By eye ↑ Magnified

- Immotile (do not move)
- Growth limited in dry conditions

Soil fungi - Example

- Moulds

↑ By eye

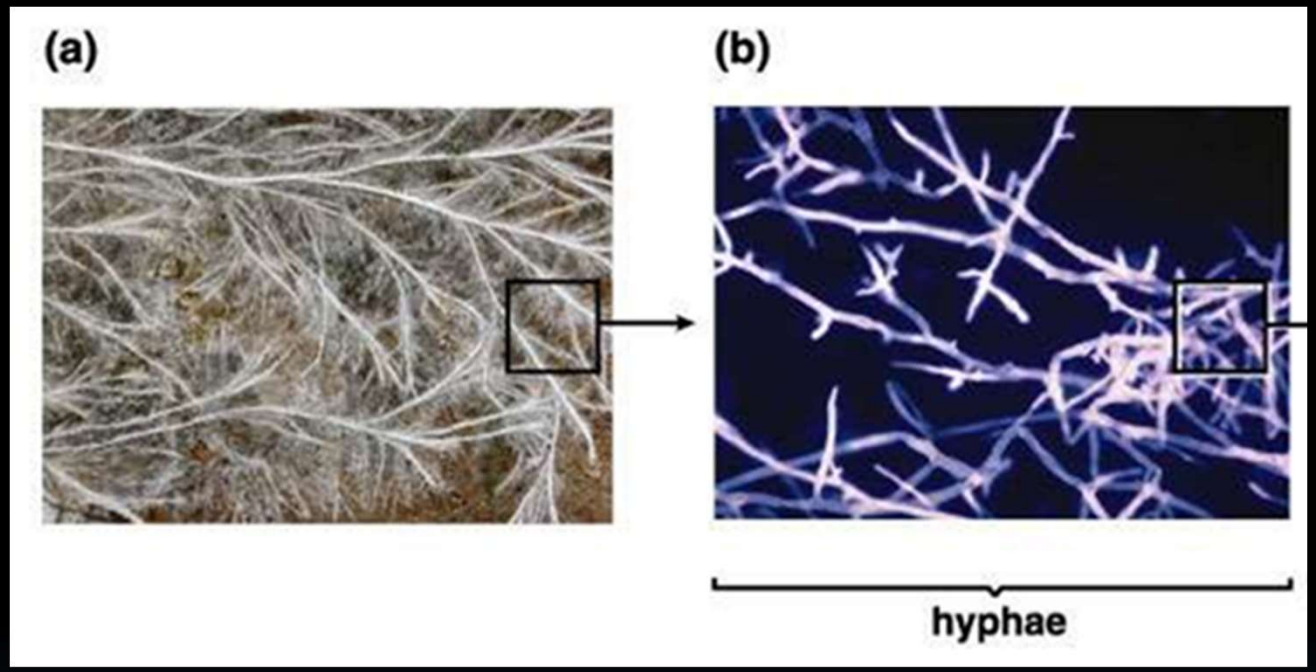


↑ Magnified

- Expand to find food source
- Growth limited in dry conditions

Soil fungi - Example

- Filamentous fungi



↑ By eye ↑ Magnified

- Rapidly explore area to find food sources
- Can remain active in dry conditions

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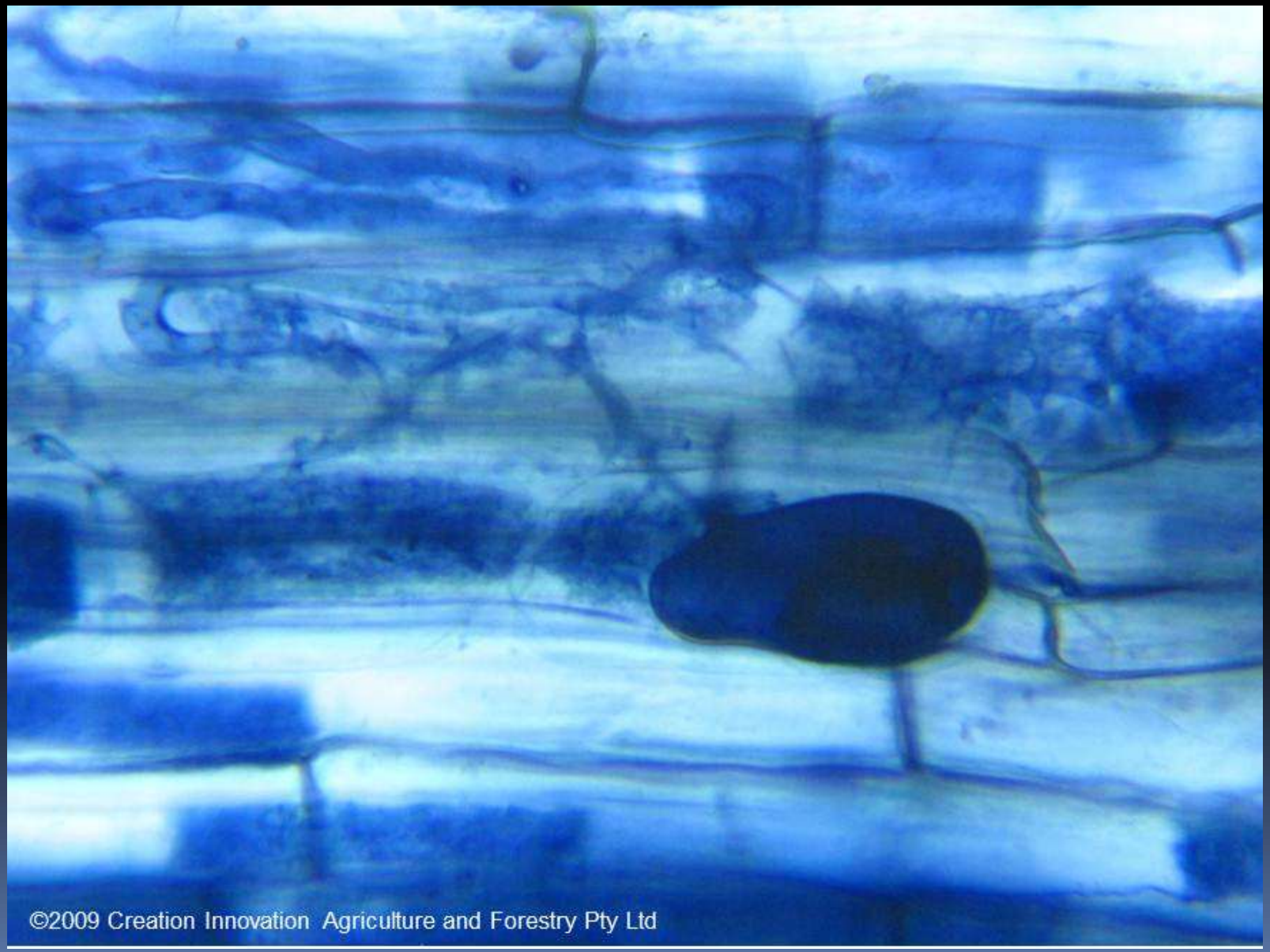
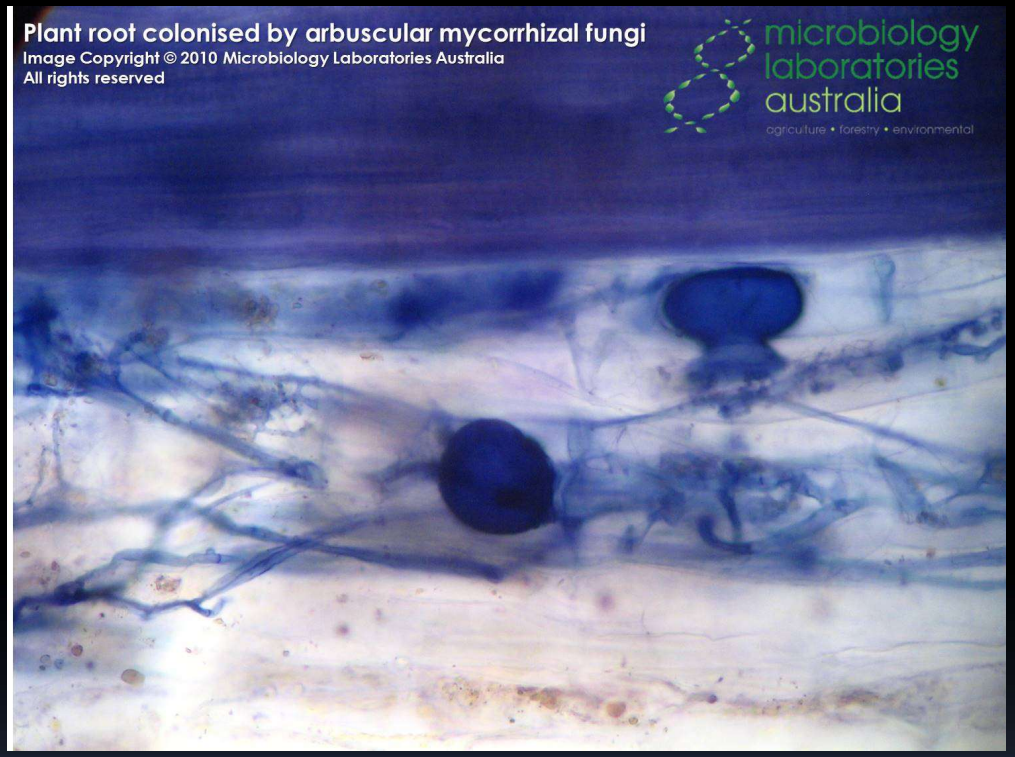
Soil fungi - Mycorrhizas

- Arbuscular mycorrhizal fungi (VAM)



Soil fungi - Mycorrhizas

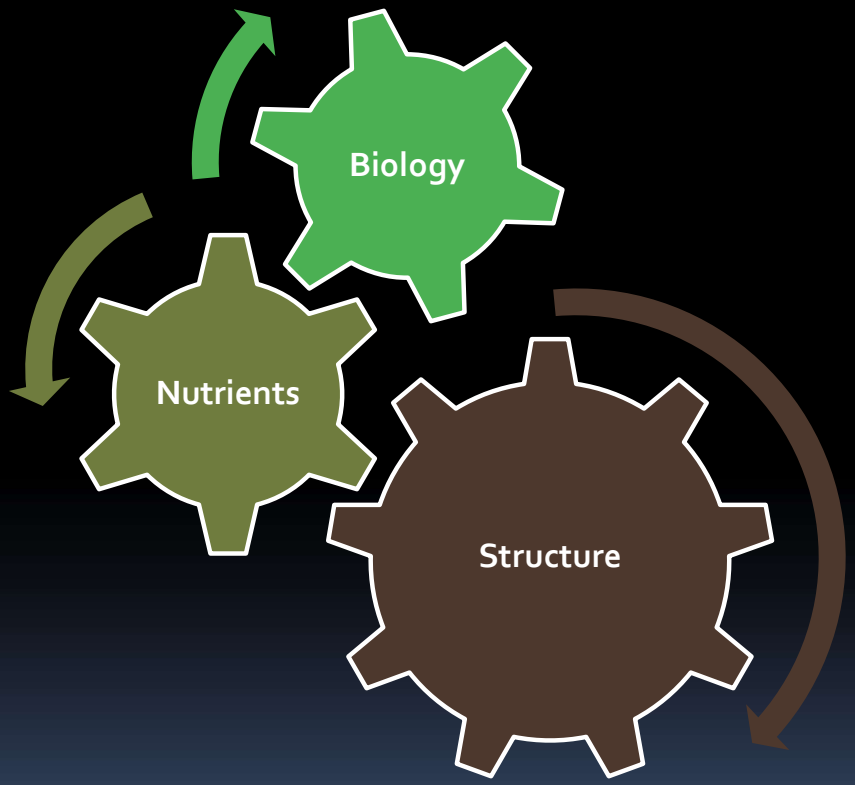
- Arbuscular mycorrhizal fungi (VAM)
  - Must live with plants
  - Get carbon from plants as sugars
  - Give nutrients to plants (esp. P)
  - Make glomalin – resistant C exudate
  - Different to other fungi
    - Plant genes unique to AM colonisation and nutrient transfer
    - Specialised structures within roots
    - Usually beneficial to plant nutrition and growth



Transition to SOIL HEALTH

Principal interactions

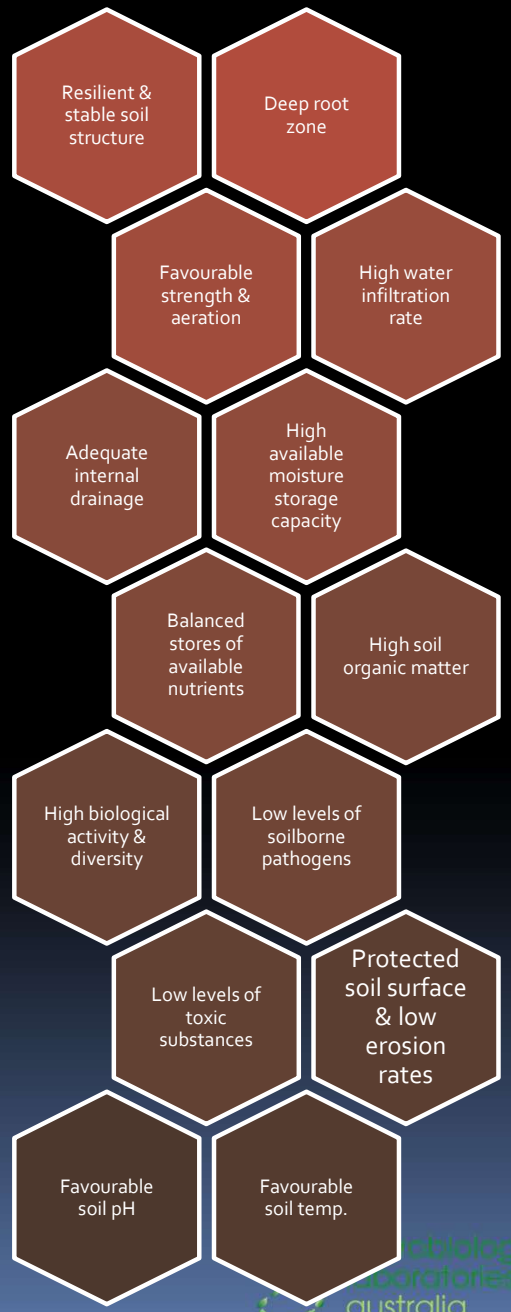
Soil components



Soil processes

- Residue digestion
- Nutrient cycling
- Soil structure maintenance
- Pest & disease regulation

Soil properties



Transition to SOIL HEALTH

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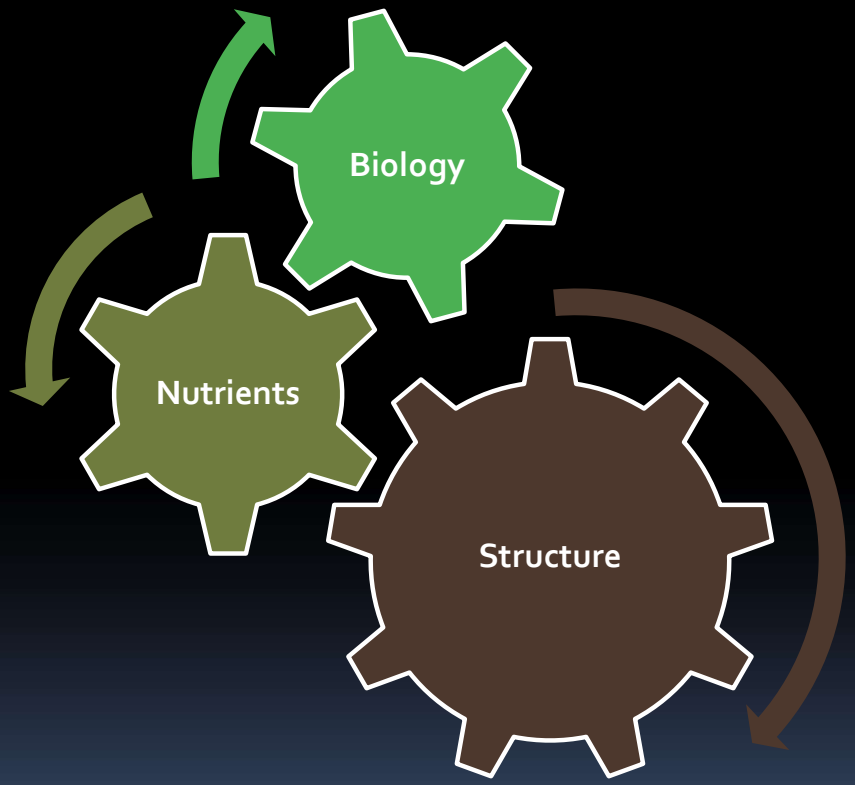

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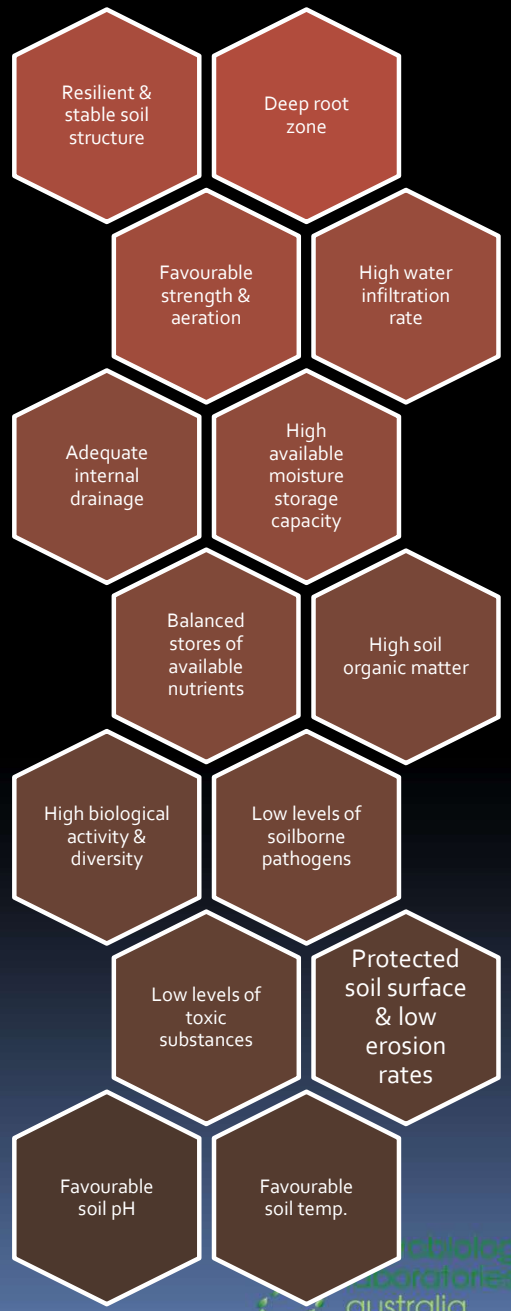
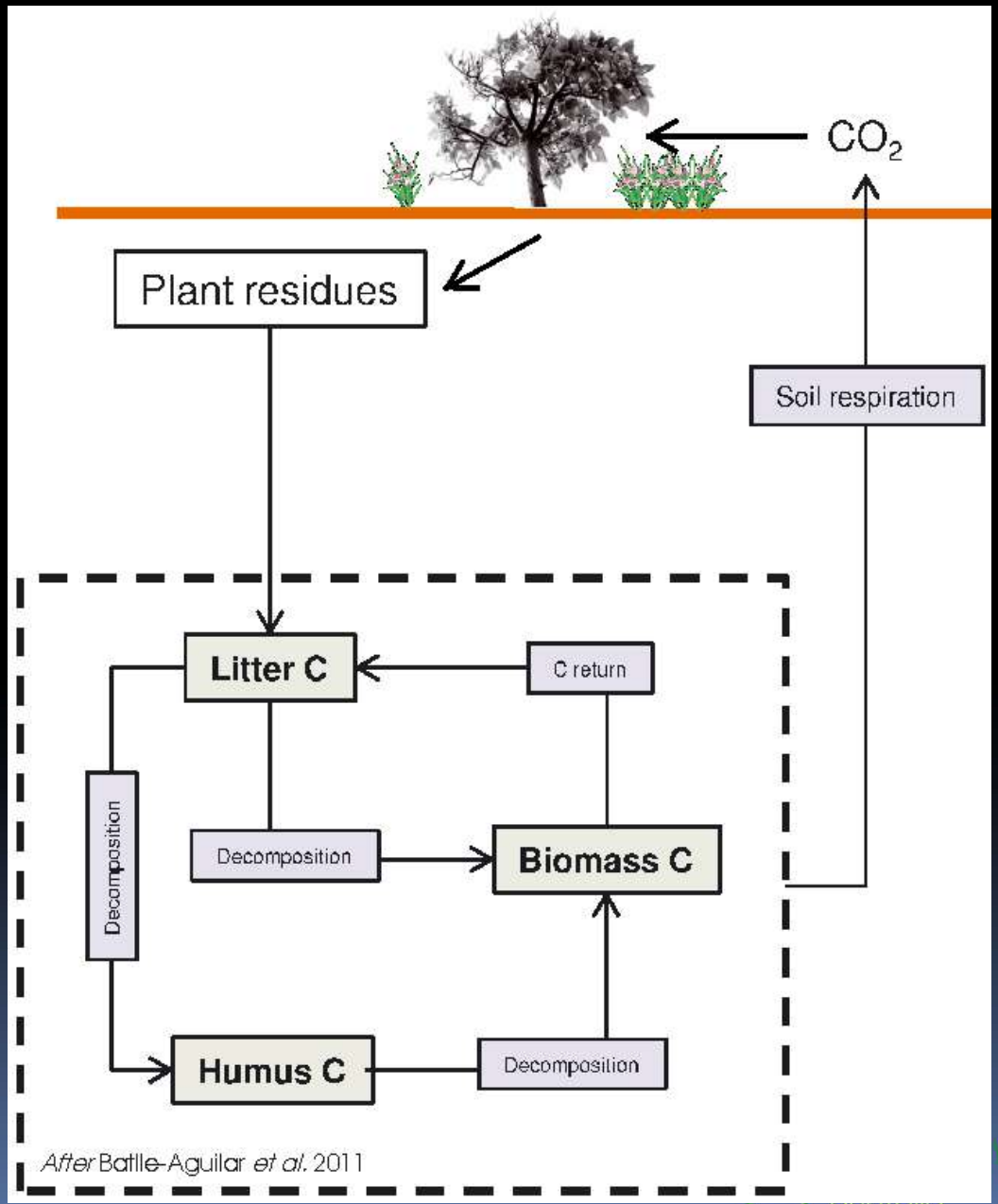


Soil C Cycle – "The Fate of C"

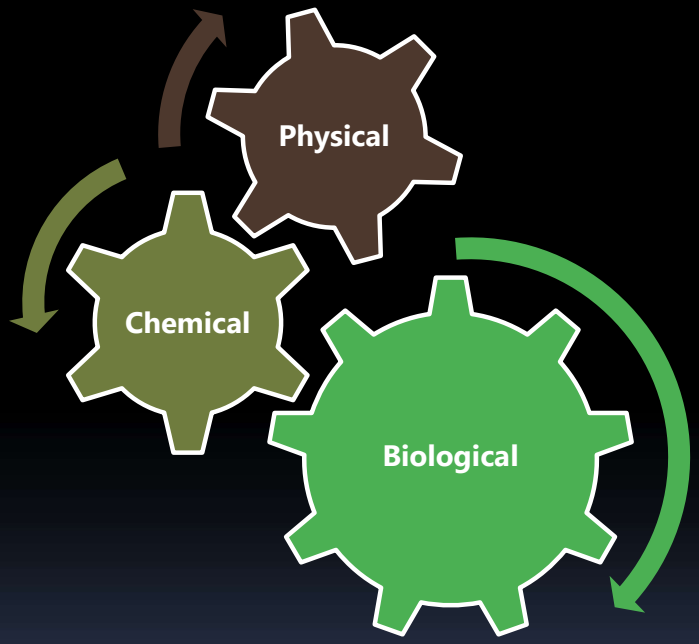
- The **"Tale of the Fate of Carbon"**
- **Digested** by microbes
- **Incorporated** into biology biomass
- **Returned** to CO2 by respiration
- **Stabilised** into humus



Transition to SOIL HEALTH

Principal interactions

Soil components complex interaction



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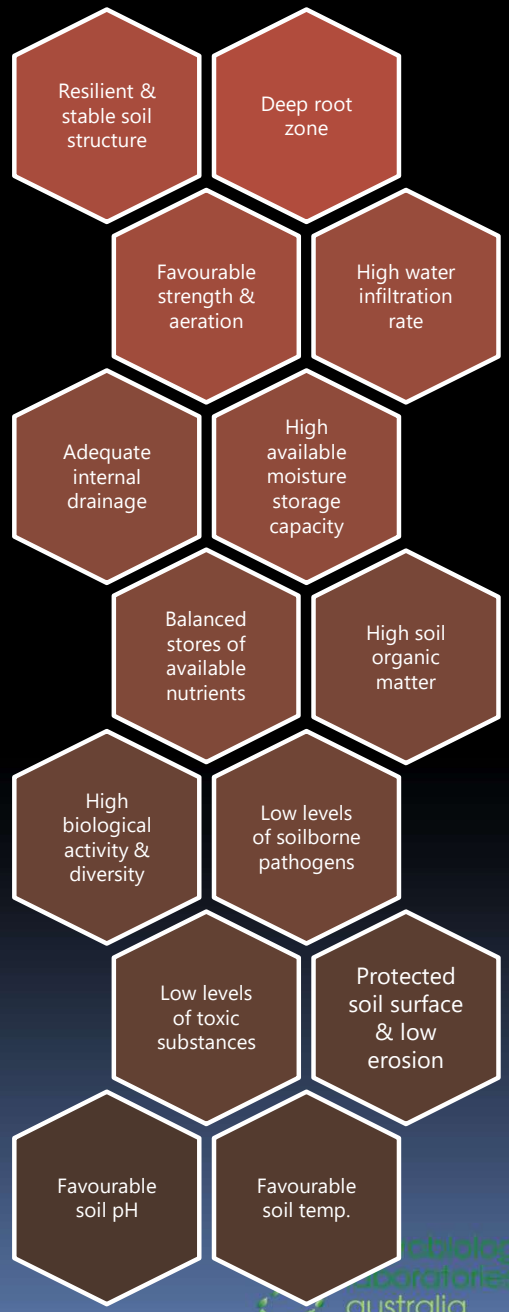

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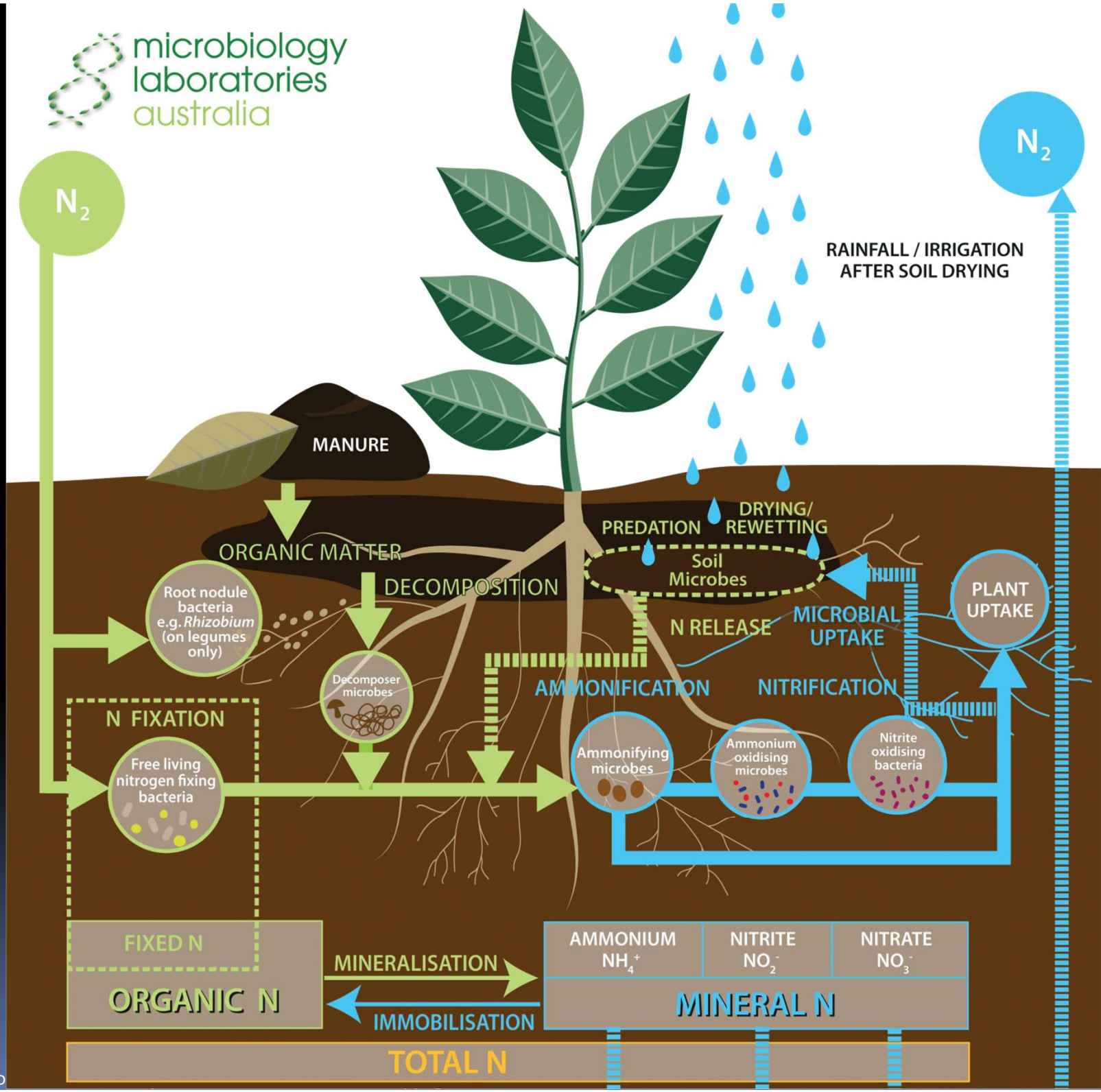
Soil nitrogen cycle



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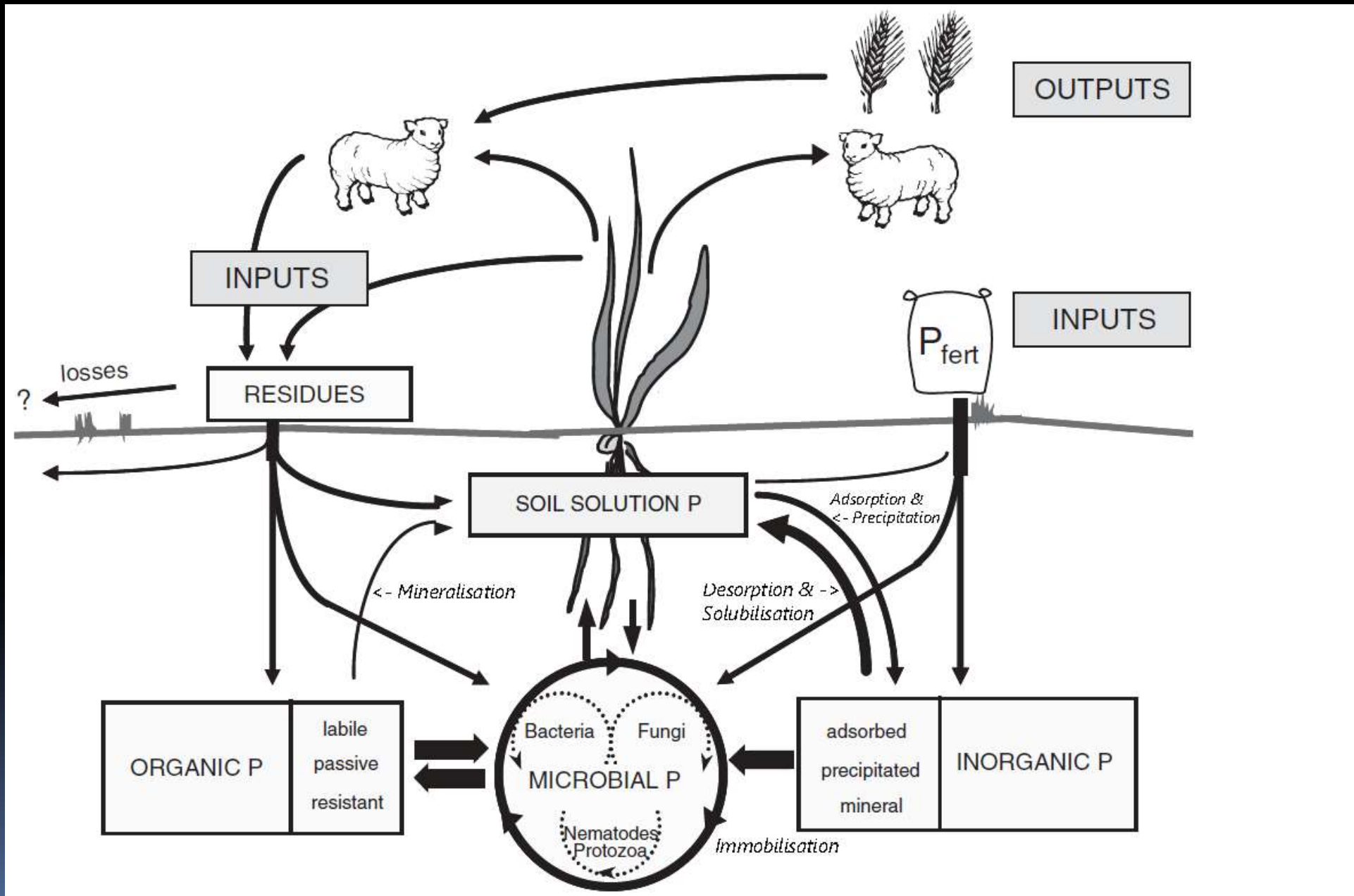
Soil phosphorus cycle



After Richardson *et al.* (2009), Crop Pasture Sci., 60:124-143

Transition to SOIL HEALTH

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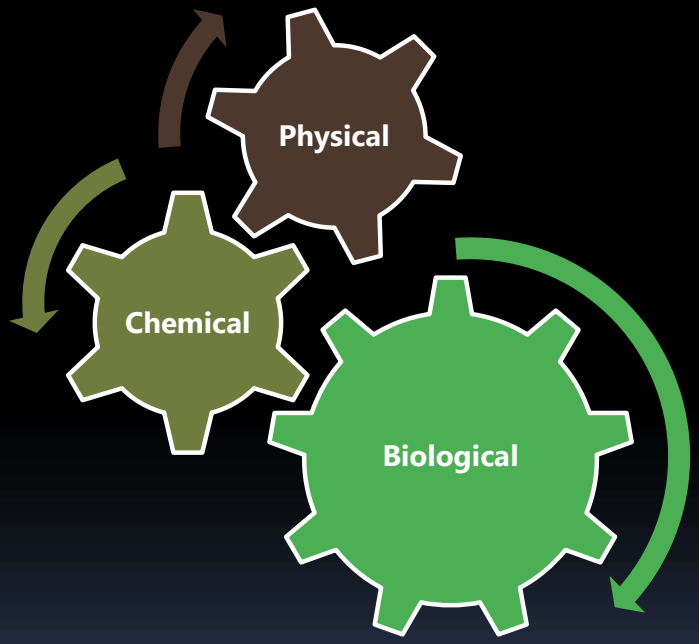

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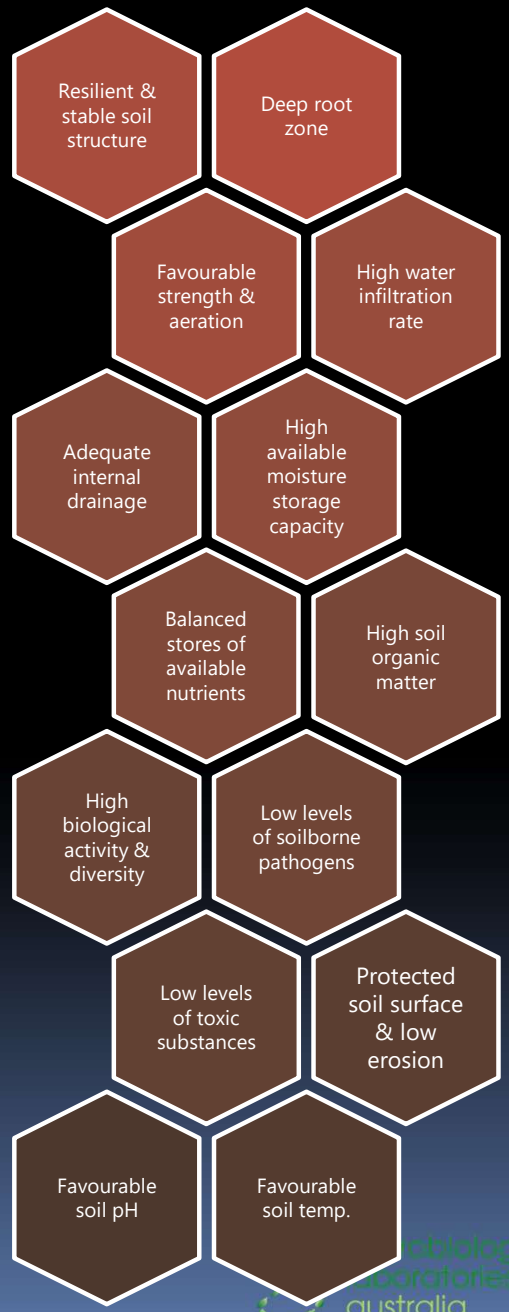

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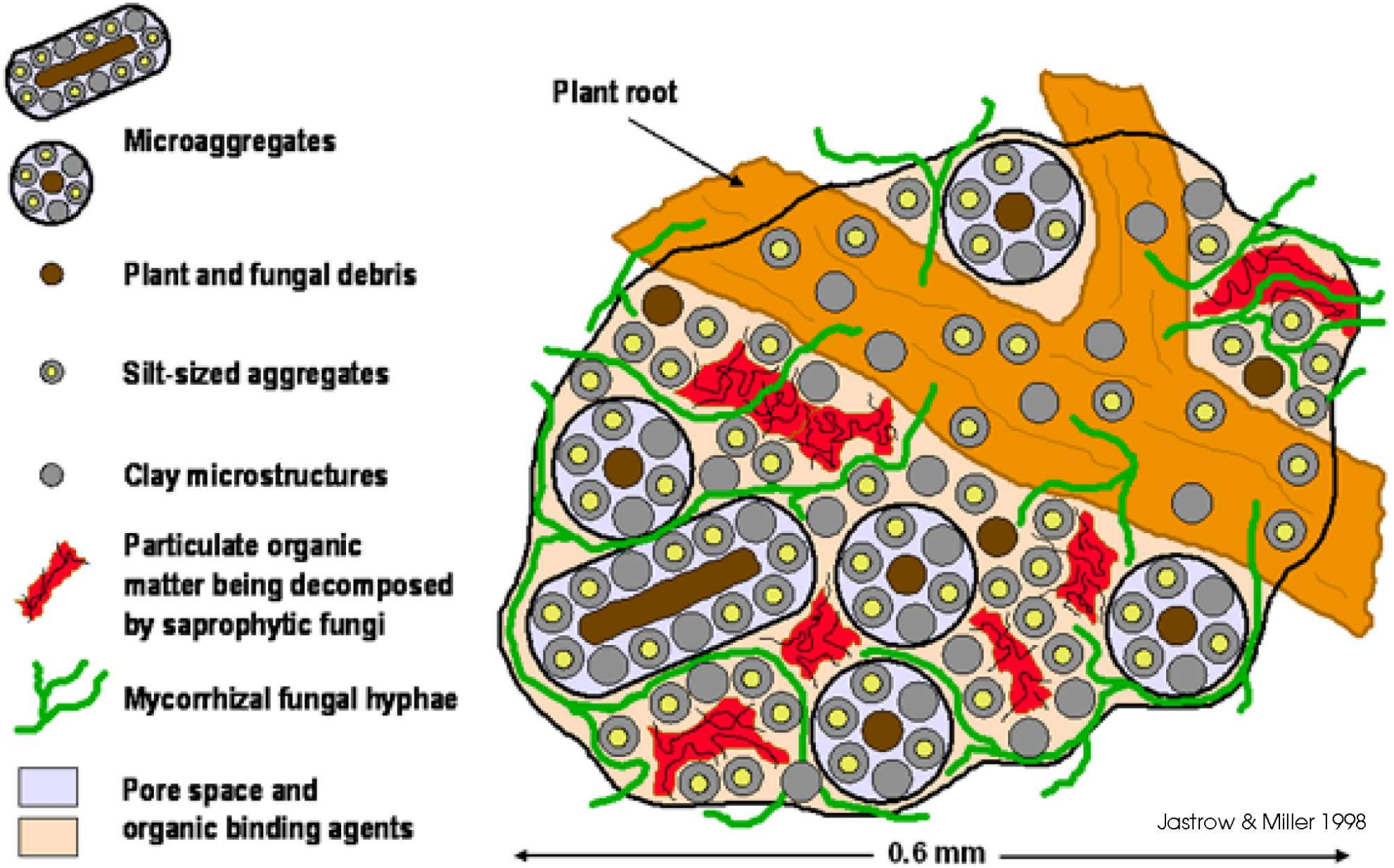
Aggregation – What is it?



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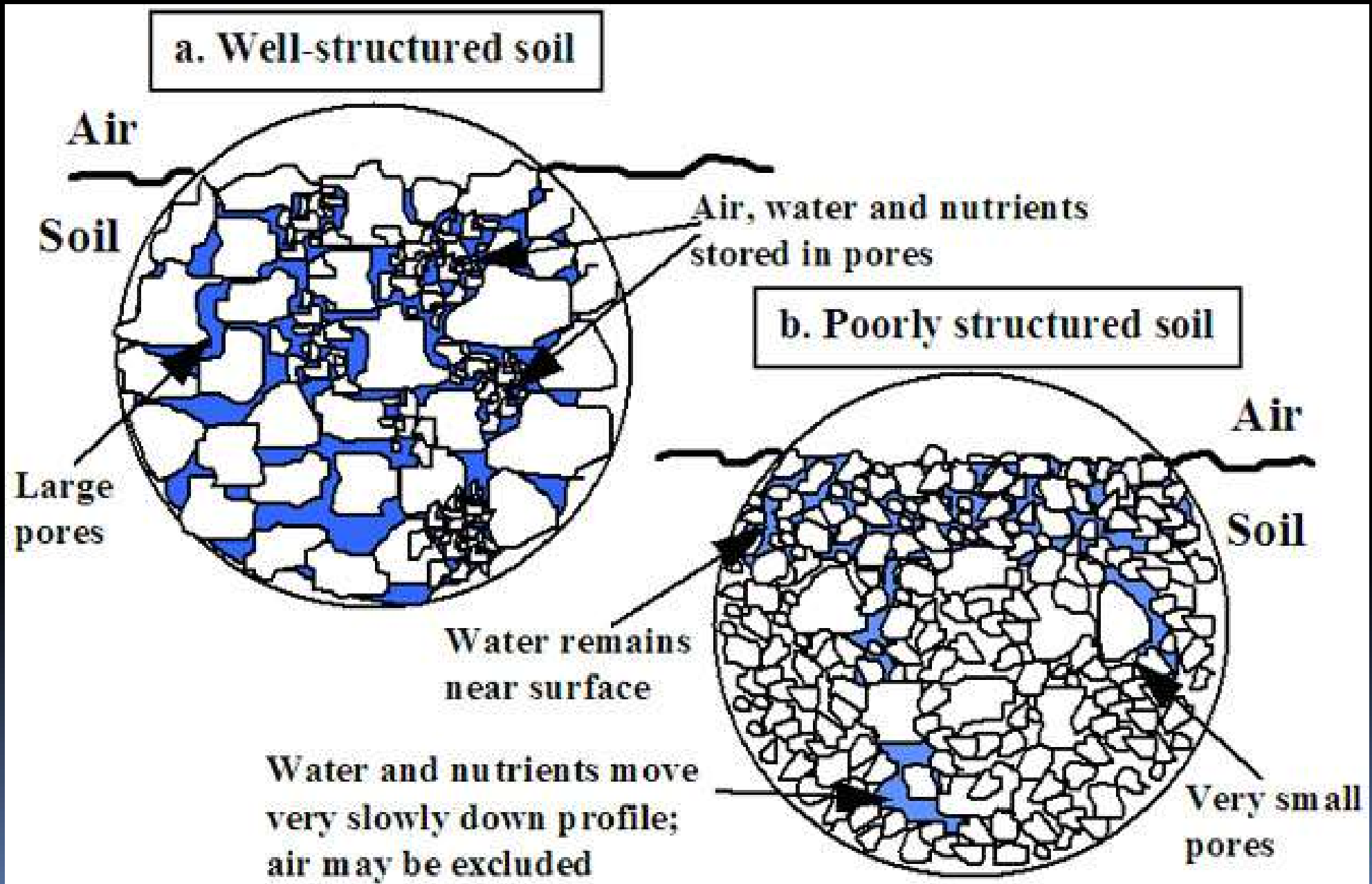
Physical constraints - Structure



Transition to SOIL HEALTH

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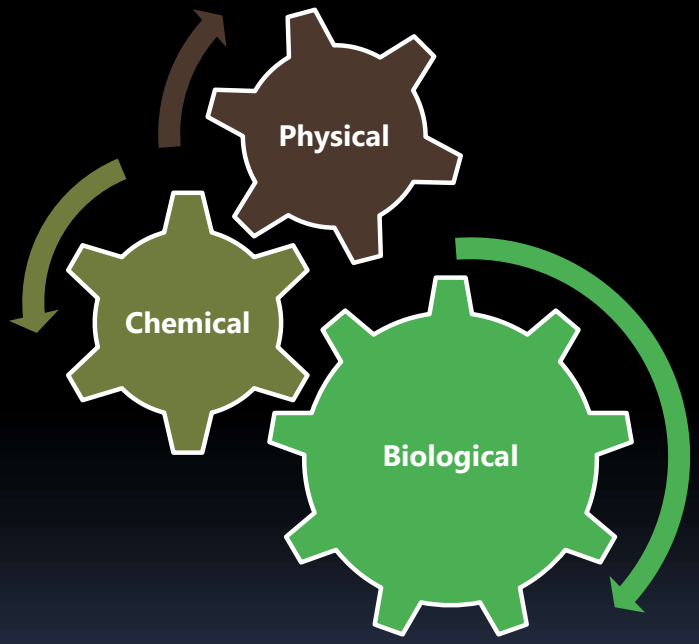

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Soil properties

- Resilient & stable soil structure
- Deep root zone
- Favourable strength & aeration
- High water infiltration rate
- Adequate internal drainage
- High available moisture storage capacity
- Balanced stores of available nutrients
- High soil organic matter
- High biological activity & diversity
- Low levels of soilborne pathogens
- Low levels of toxic substances
- Protected soil surface & low erosion
- Favourable soil pH
- Favourable soil temp.

Transition to SOIL HEALTH

Why do we have soilborne disease?

- **Biological**
  - Low diversity
  - Low biomass
  - Low beneficials
- **Chemical**
  - Fertiliser
    - Rates
    - Form
      - NH_4- and NO_3- modify soil pH
- **Physical**
  - Poor structure
    - Compaction
    - Waterlogging
    - Drainage

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Transition to SOIL HEALTH

Interactions

Interactions Between Soil Carbon, Nutrients & Biology

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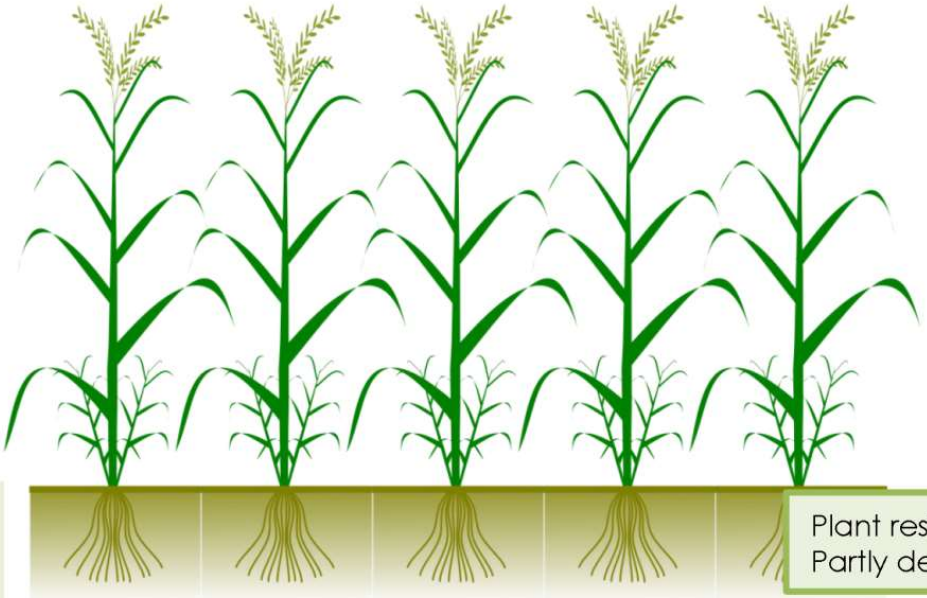
agriculture • forestry • environmental



Labile Carbon
Typical range 5-50% of Total C
Sensitive indicator of soil fertility
Highly affected by farming practices
E.g. ≈30% difference between residue burning/not burning

Non-labile Carbon
(Resistant C)

Recalcitrant Carbon

Plant residues
Partly decomposed residues

Benefits
Soil structure
- Infiltration
- Moisture holding
- Aeration
- Tilth

Nutrient solubilisation
Nutrient cycling
Disease resistance
Drought resistance
Nutrient accessibility
Residue breakdown
System resilience
Biological fertility
> Predictable outcomes

Soil Microbes
Microbial Biomass Carbon

Glomalin
Humus

N
P
Other nutrients

Nutrients released when soil C:N < 22:1

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Transition to SOIL HEALTH

General microbiology

Group	Biomass (mg/kg) Yours	Guide
Total microorganisms	26.2	50.0
Total bacteria	4.5	15.0
Total fungi	20.7	33.8

Microbial indicators	Yours	Guide
Microbial diversity	34.1	80.0
Fungi : Bacteria	4.6	2.3
Bacterial stress	0.2	< 0.5

Key *BDL = Below Detectable Limit (0.001 mg/kg)

Poor Fair Good

Group	Biomass (mg/kg) Yours	Guide
Bacteria		
Pseudomonas	0.806	1.000
Actinomycetes	0.527	1.000
Gram positive	2.070	4.000
Gram negative	2.403	11.000
Methane oxidisers	0.000	0.500
Sulphur reducers	0.000	< 0.005
True anaerobes	0.153	< 0.005
Eukaryotes		
Protozoa	1.002	1.300
Mycorrhizal fungi (including VAM)	10.391	10.000

Comments

The soil indicators ranged from fair to good. The total mass of microbes in your sample was fair. Biomasses of other key desirable microbe groups ranged from poor for gram negative bacteria and actinomycetes to good. Protozoa, which were good here, are important for nutrient transfer and cycling between soil trophic levels, and can be sensitive to agrochemicals, particularly herbicides. True anaerobes were elevated, which indicates that this soil was recently waterlogged, or compacted. Microbial diversity was fair. The fungi to bacteria ratio was elevated that need to be balanced. These results suggest that management practices should initially focus on building microbial diversity. Re-test periodically, and once biomass has improved concentrate on minimising True anaerobes, building microbial diversity and biomasses of any key desirable groups that remain low.

Explanations

Microbe Wise for Soil measures the living biomass of key microbial groups important for soil health and productivity directly from your sample. It uses molecular ('DNA type') technology to analyse the unique cell membrane 'fingerprint' of each microbe group to identify and quantify well-known microbial groups essential to important soil processes. The Microbe Wise method allows for some unique features, such as a measure of microbial diversity, a valuable indicator of soil system resilience. Results are presented in a way that allows you to easily assess the microbial health of your soil in detail and indicates what that means in practice. Always compare your results with a control sample. Guide values are included as a help, but because a large number of factors affect microbiology the guide levels may not be optimal for your specific conditions. Visit www.microbelabs.com.au for more information.

MICROBE WISE FOR SOIL

- Good value
- Good overview of soil microbial health
- Measures key soil health groups
- Practical soil indicators
- Good for benchmarking soil microbial status

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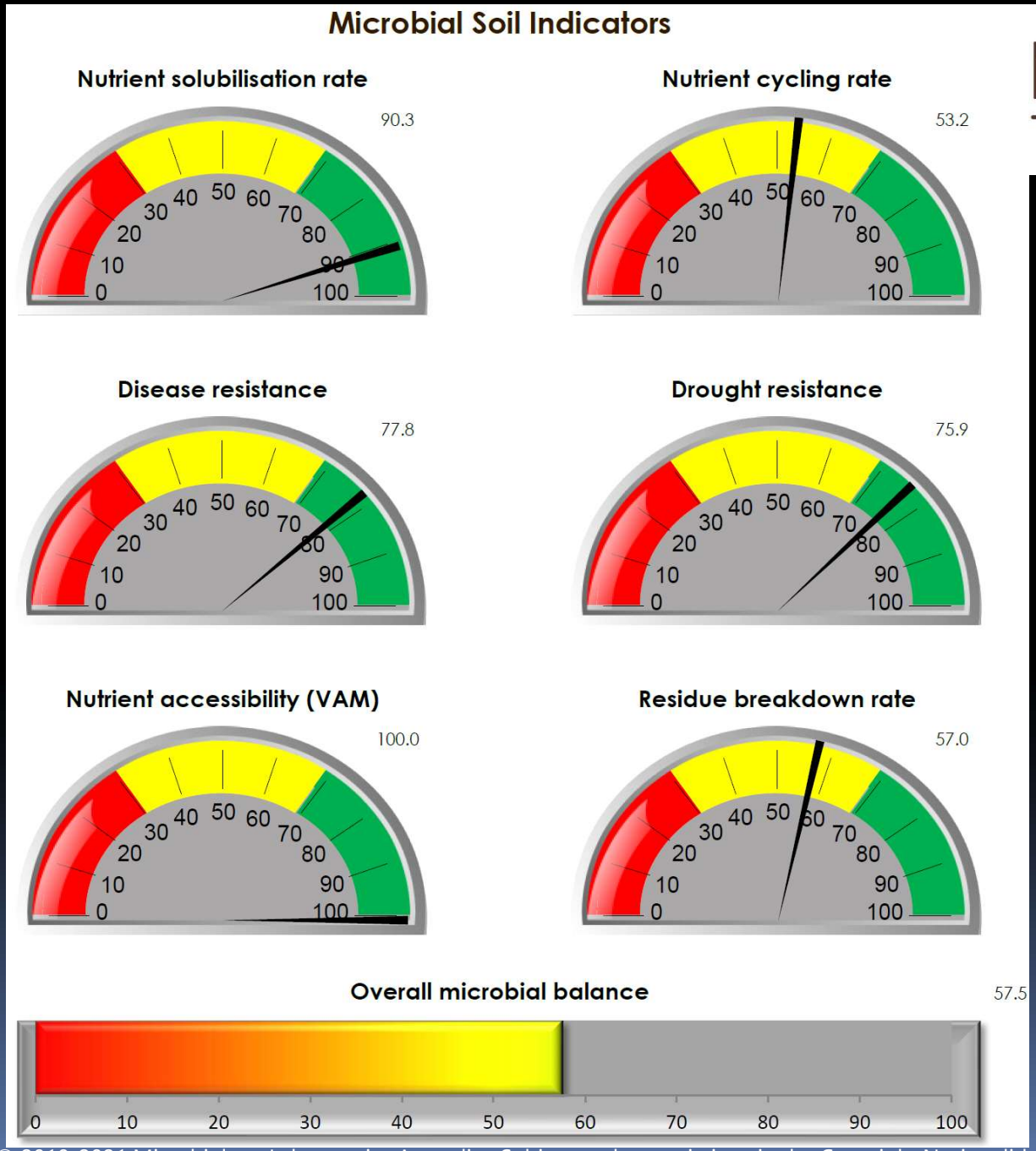
Transition to SOIL HEALTH

General microbiology



MICROBE WISE FOR SOIL

- Good value
- Good overview of soil microbial health
- Measures key soil health groups
- Practical soil indicators
- Good for benchmarking soil microbial status

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Transition to SOIL HEALTH

General microbiology

Group	Biomass (mg/kg) Yours	Guide
Total microorganisms	26.2	50.0
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Eukaryotes		
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Comments

The soil indicators ranged from fair to good. The total mass of microbes in your sample was fair. Biomasses of other key desirable microbe groups ranged from poor for gram negative bacteria and actinomycetes to good. Protozoa, which were good here, are important for nutrient transfer and cycling between soil trophic levels, and can be sensitive to agrochemicals, particularly herbicides. True anaerobes were elevated, which indicates that this soil was recently waterlogged, or compacted. Microbial diversity was fair. The fungi to bacteria ratio was elevated that need to be balanced. These results suggest that management practices should initially focus on building microbial diversity. Re-test periodically, and once biomass has improved concentrate on minimising True anaerobes, building microbial diversity and biomasses of any key desirable groups that remain low.

Explanations

Microbe Wise for Soil measures the living biomass of key microbial groups important for soil health and productivity directly from your sample. It uses molecular ('DNA type') technology to analyse the unique cell membrane 'fingerprint' of each microbe group to identify and quantify well-known microbial groups essential to important soil processes. The Microbe Wise method allows for some unique features, such as a measure of microbial diversity, a valuable indicator of soil system resilience. Results are presented in a way that allows you to easily assess the microbial health of your soil in detail and indicates what that means in practice. Always compare your results with a control sample. Guide values are included as a help, but because a large number of factors affect microbiology the guide levels may not be optimal for your specific conditions. Visit www.microbelabs.com.au for more information.

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Transition to SOIL HEALTH

How to interpret a Microbe Wise test

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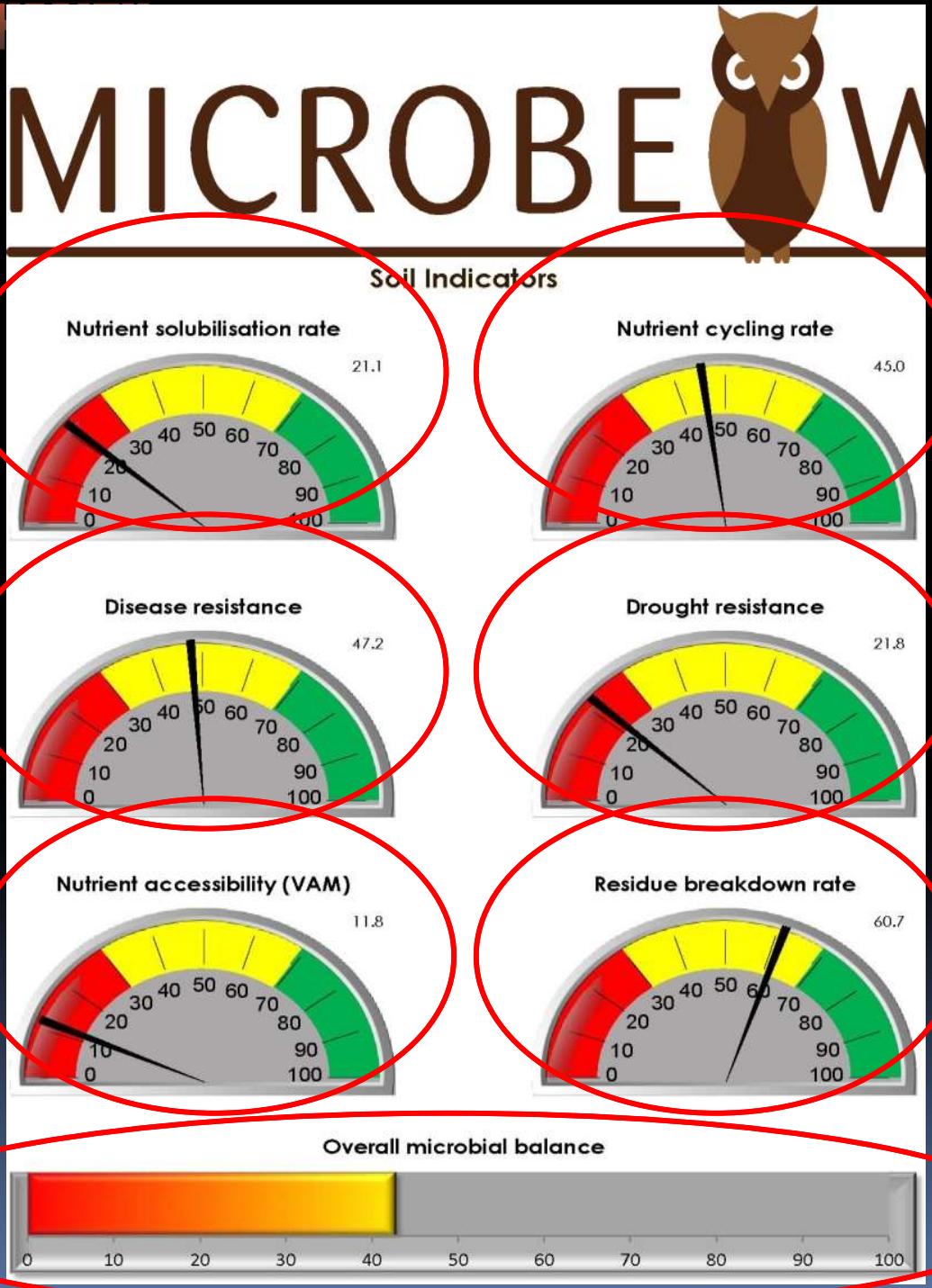
Page 1



- Soil Indicators
  - Indicate key soil processes
    - P-solubilisation
    - Nutrient cycling
    - Disease resistance
    - Drought resistance
    - Residue breakdown
    - Soil process resilience(Overall Microbial Balance)

Transition to SOIL HEALTH

Page 2

MICROBE WISE

Total bacteria ≈ millions/kg

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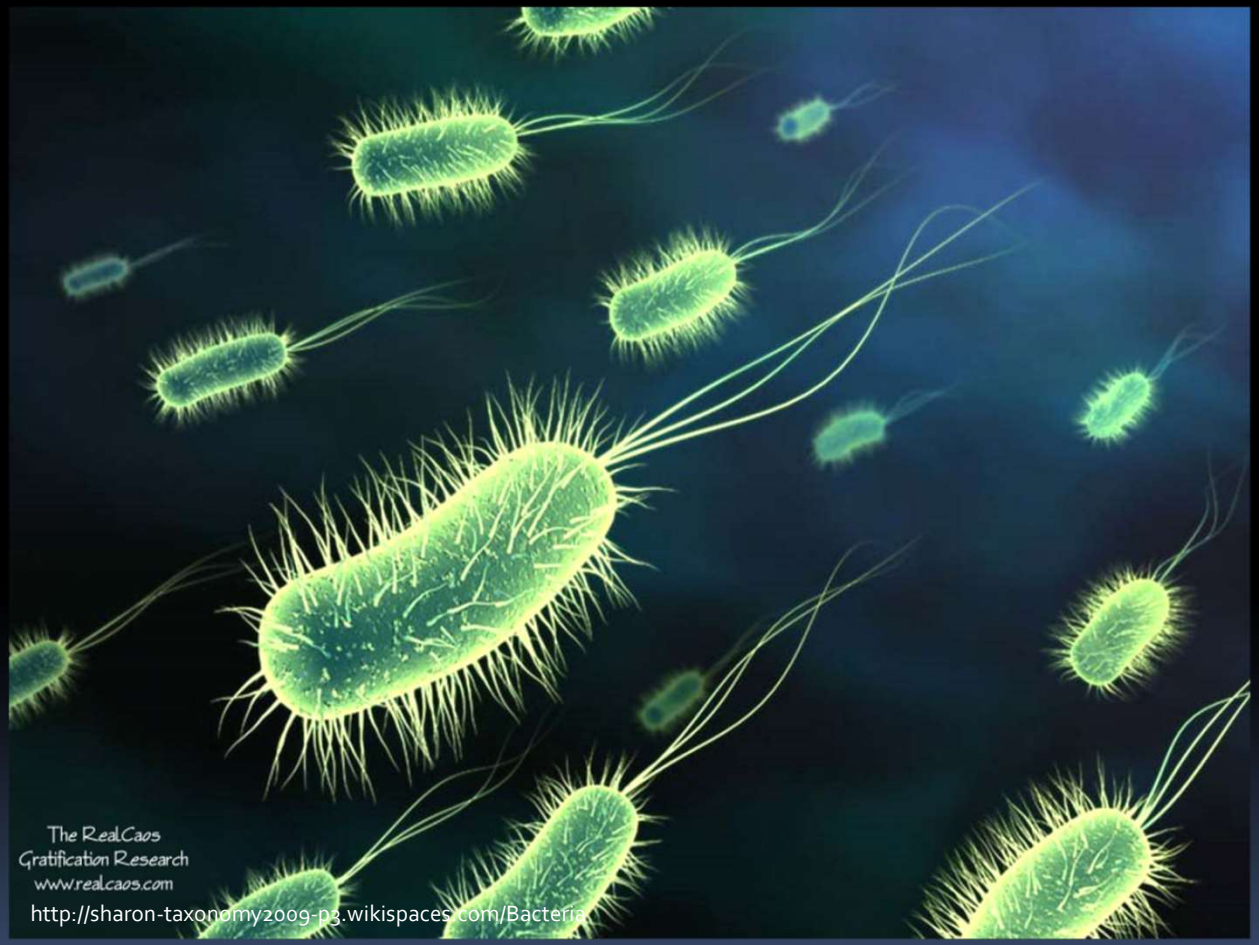
Bacteria

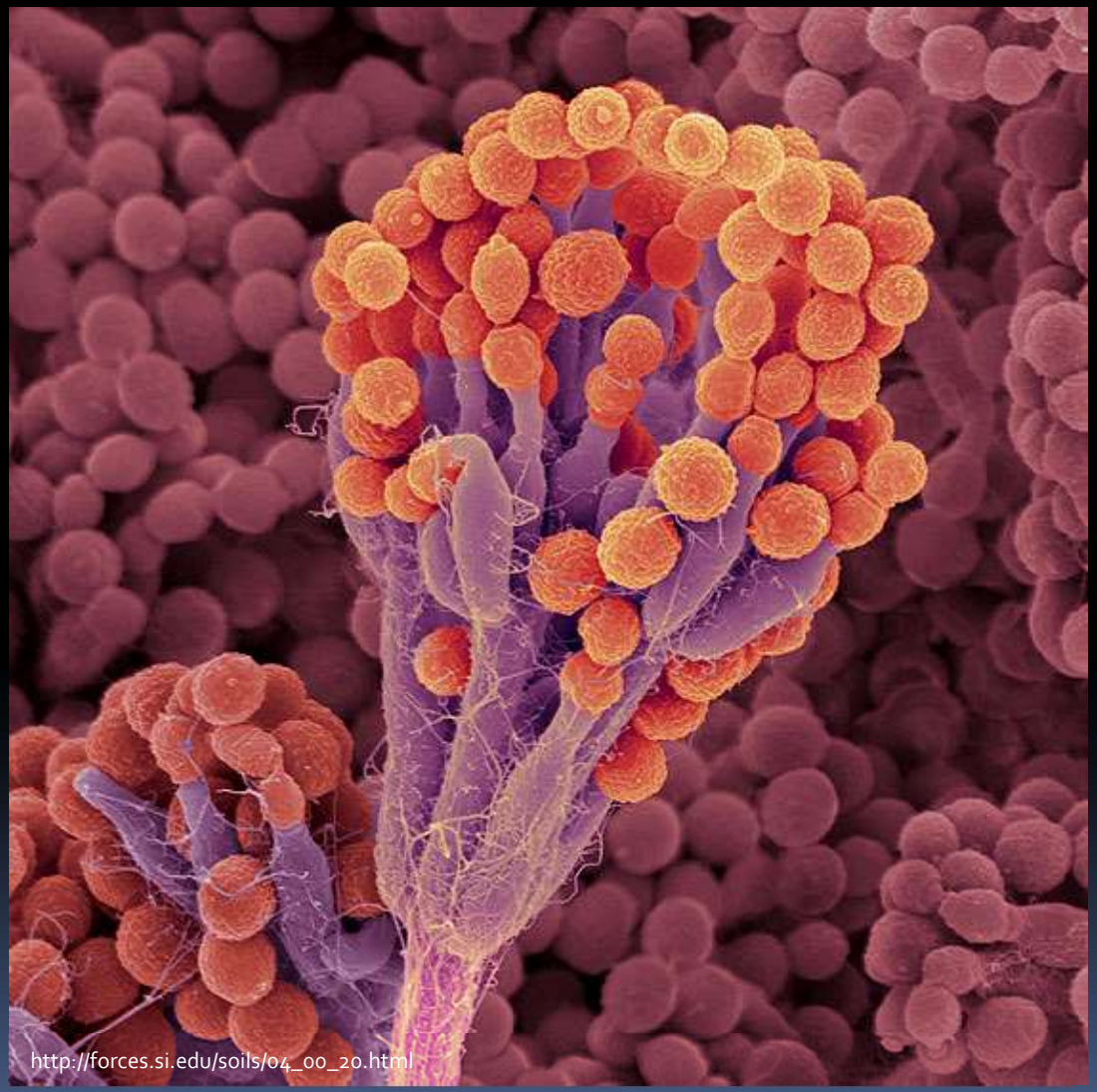


Flagellate bacteria

- Many roles
- Nutrient solubilisation
- Disease suppression
- Nitrogen fixation
- Nitrogen cycling
- Simple carbohydrate

Transition to SOIL HEALTH

Fungi



Penicillium notatum

- Release N from organic matter during breakdown
- Increase plant growth (mycorrhizas)
- Disease suppression (*Trichoderma* spp.)
- Nitrogen cycling
- Live off sugars released from complex OM

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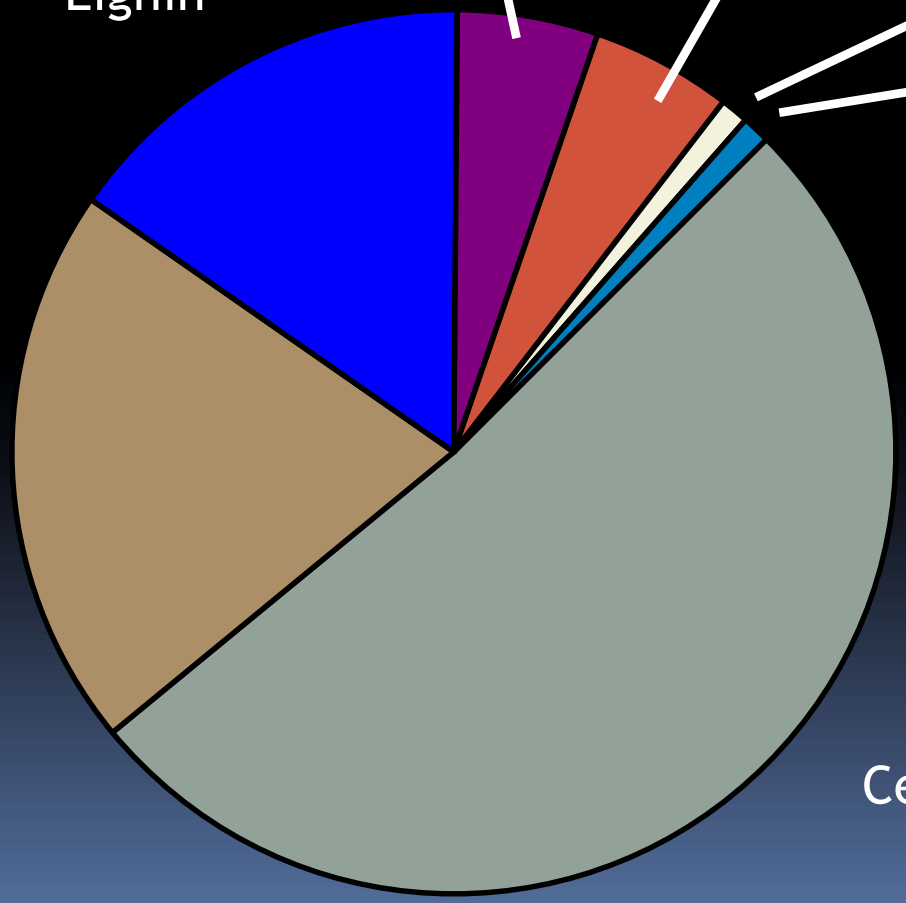
Plant residue composition



Main microbe groups that use different carbon forms

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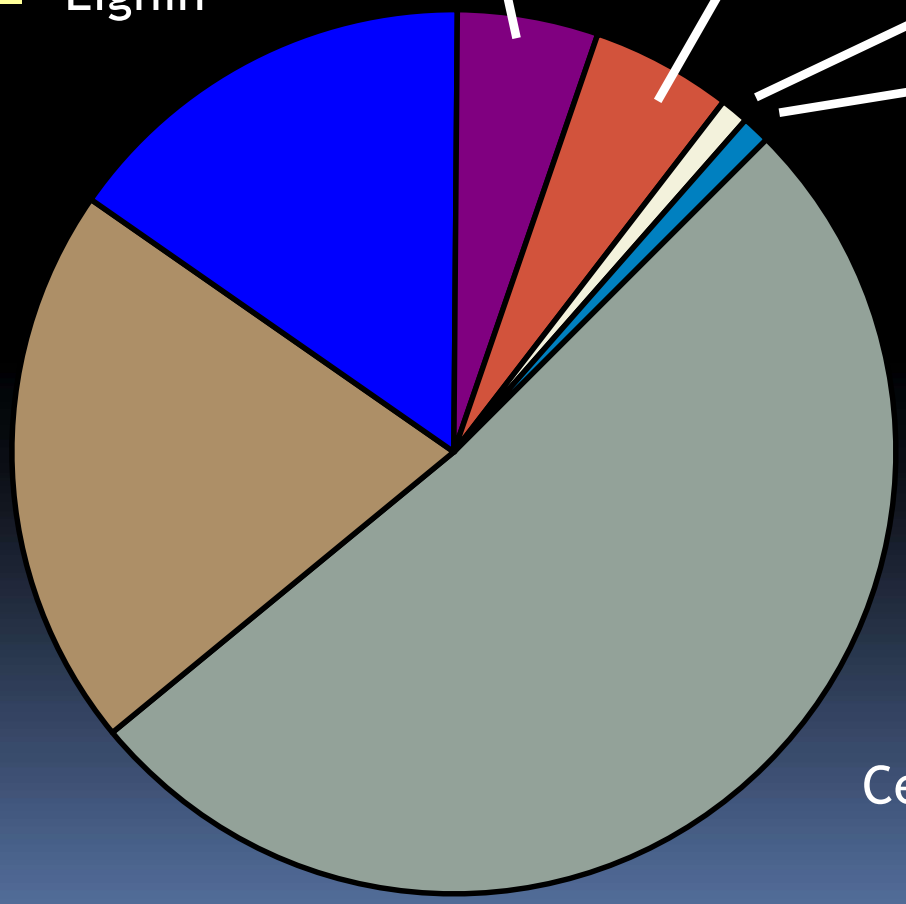

Decomposition rate of carbon forms

Transition to SOIL HEALTH

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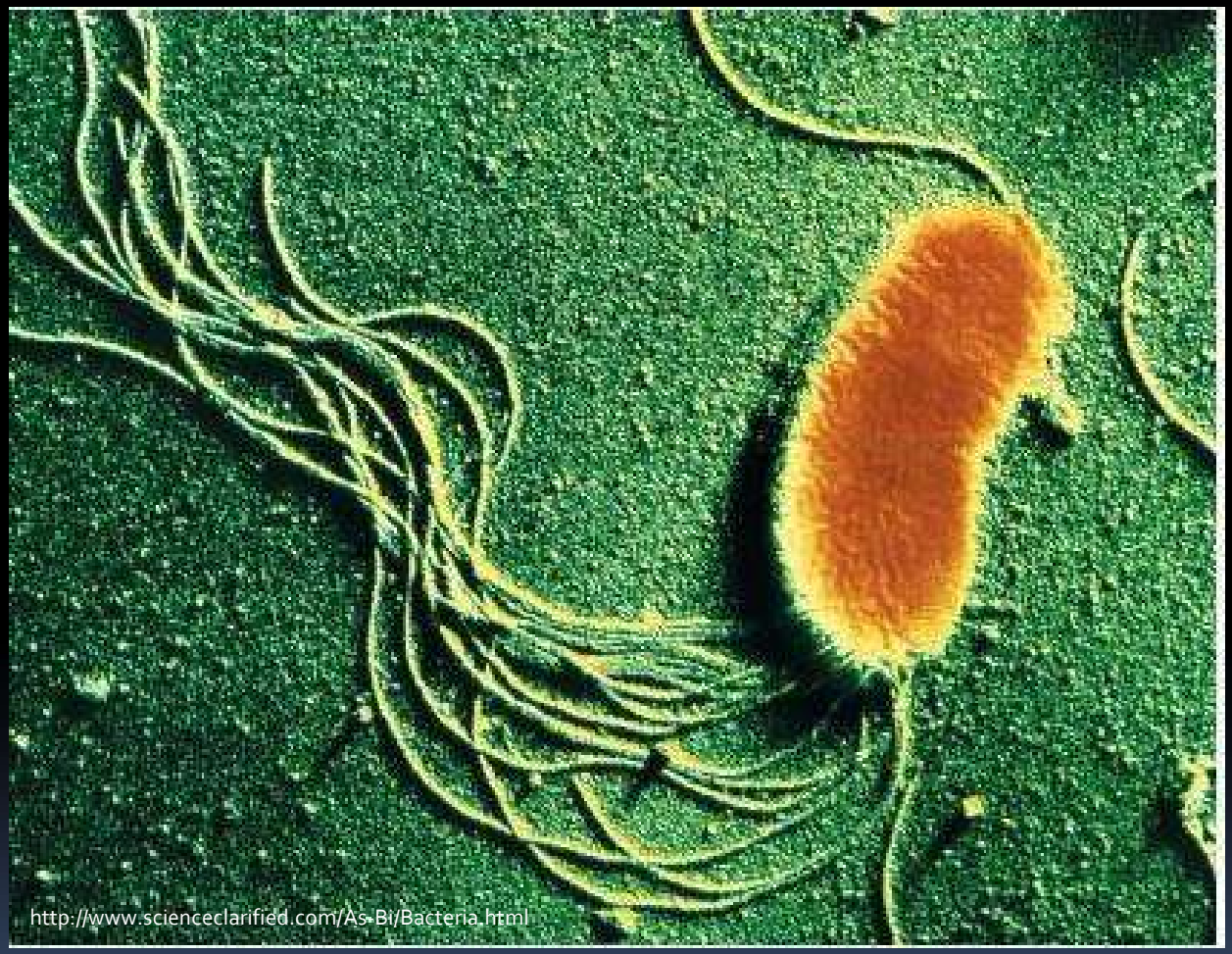
Pseudomonas



Pseudomonas fluorescens

- Solubilise P
- Antagonistic to other microbes
- Produce antibiotic compounds
- Thrive in places with high nutrient availability
- Sensitive to some herbicides

Transition to SOIL HEALTH

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Actinomycetes

http://voxhortus.wordpress.com/category/botany/

Streptomyces spp.

- Break down organic matter
- Release nutrients (N)
- Produce antibiotic compounds
- Responsible for 'rain' smell of soil

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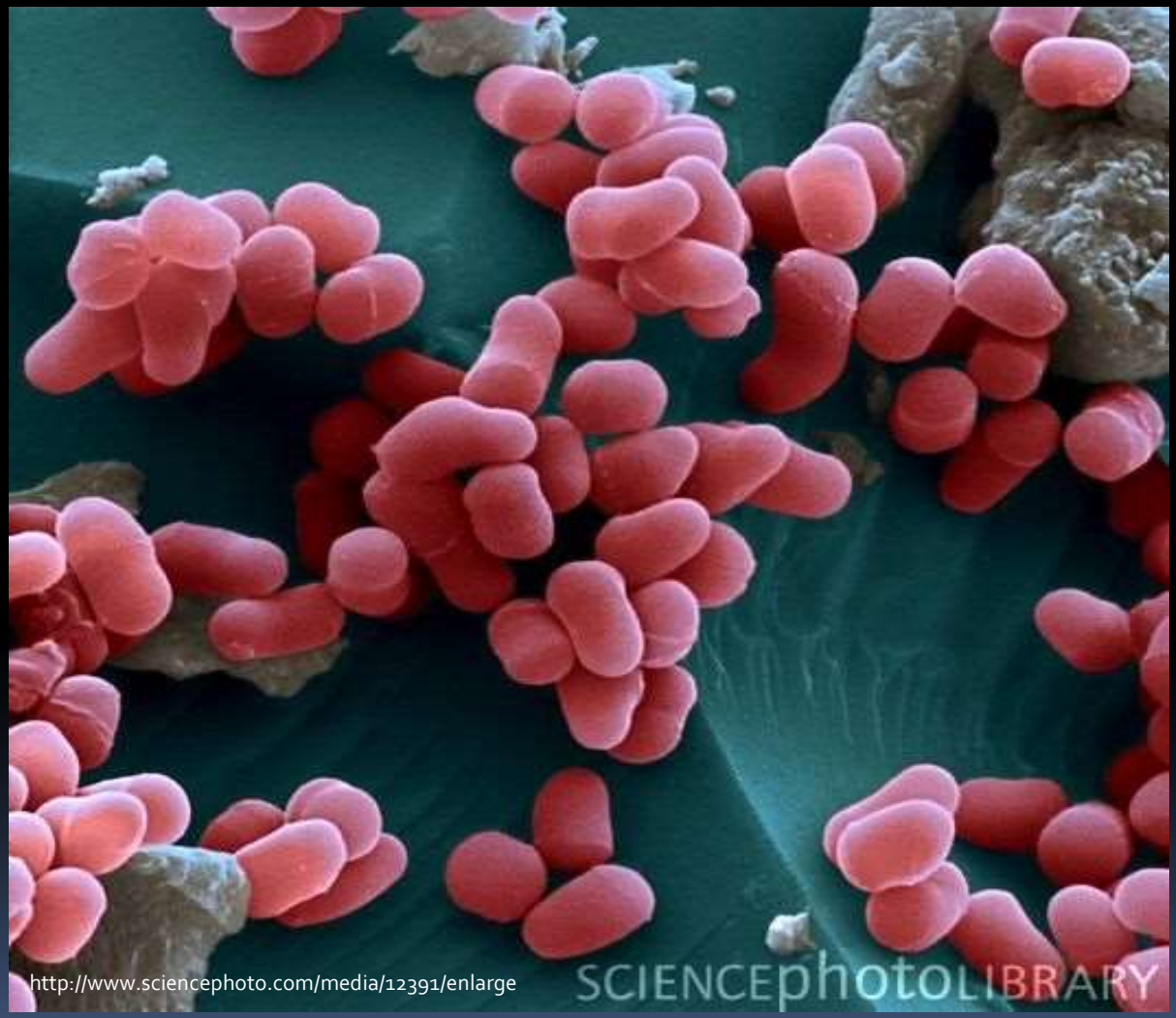
Gram Positive (+ve) bacteria



Arthrobacter crystallopoietes

- Metabolise > complex C than Gram -ve
- Less sensitive to water stress
- Slower growing
- Lower nutrient environments
- *Actinomycetes*
- *Bacillus*

Transition to SOIL HEALTH

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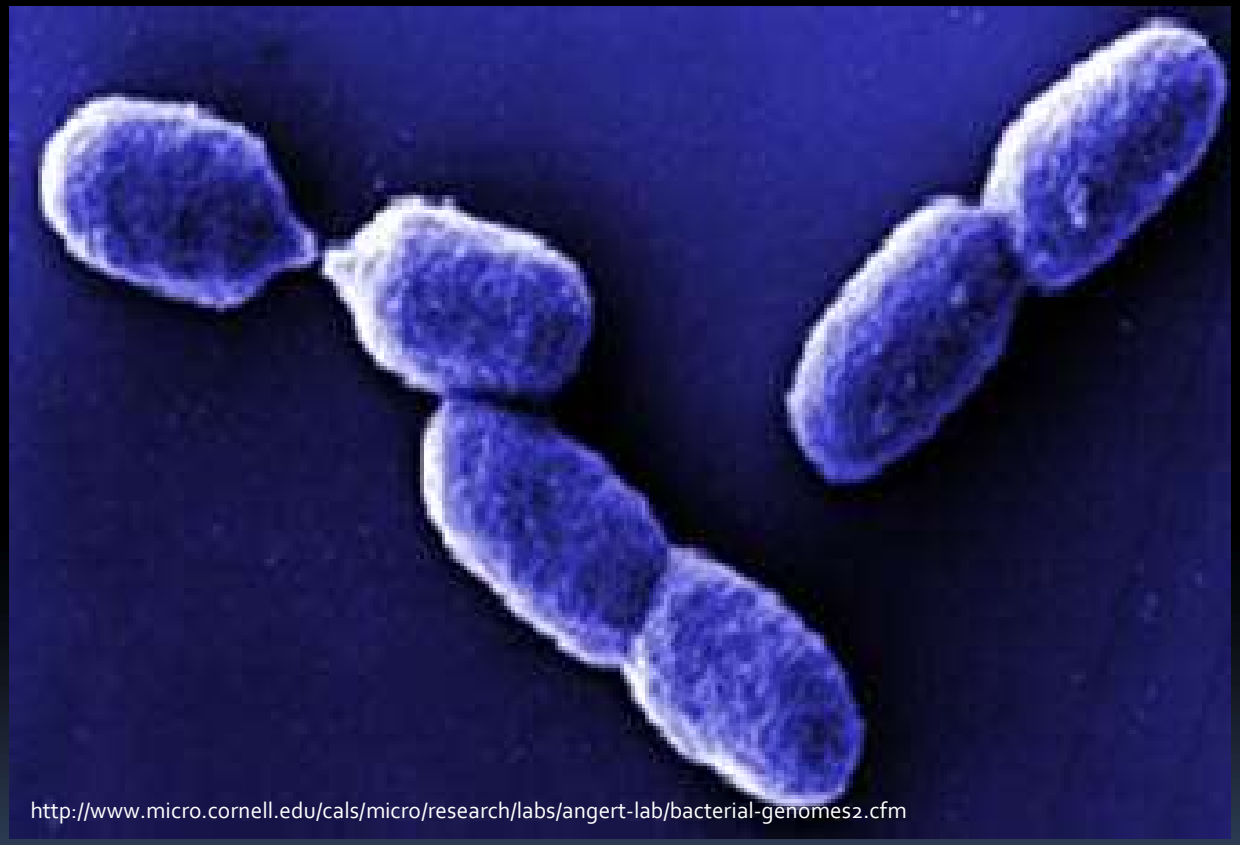
Gram Negative (-ve) bacteria



Azotobacter sp.

- Metabolise < complex C than Gram +ve
- More sensitive to water stress
- Faster growing
- Higher nutrient environments
- *Pseudomonas*
- *Azotobacter (N)*

Transition to SOIL HEALTH

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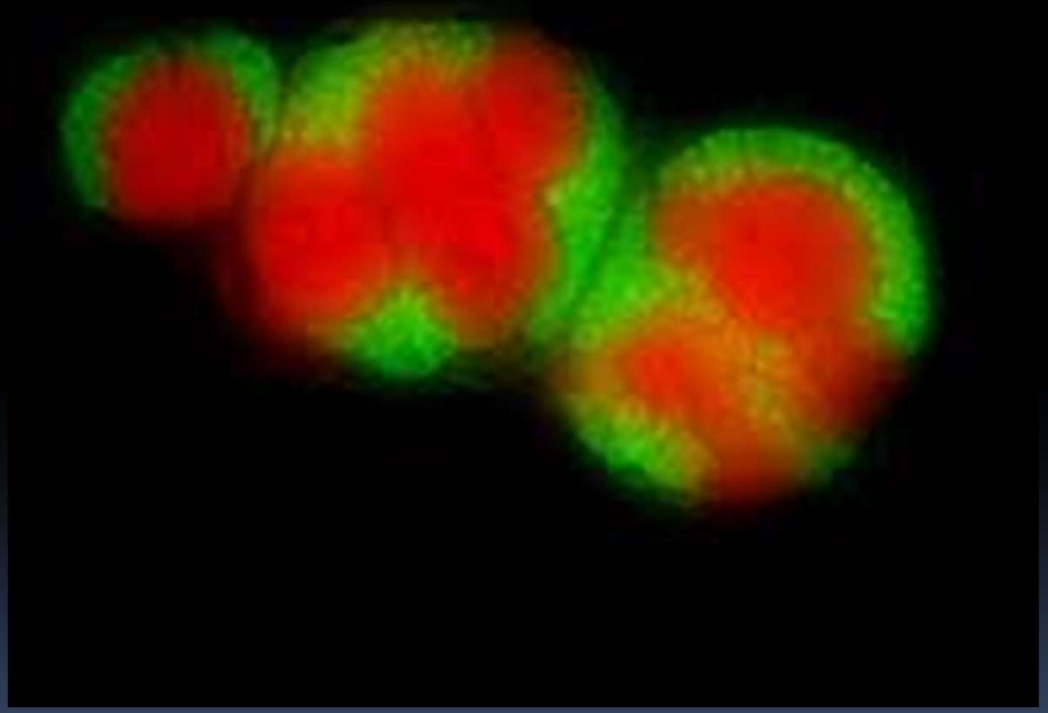
Transition to SOIL HEALTH

Methane oxidisers



- Detoxify environmental contaminants
  - E.g. Chloro-hydrocarbons
- Use methane as primary food source
- Useful for environments with high methane
  - E.g. pastures
- Indicator of polluted/ contaminated environments

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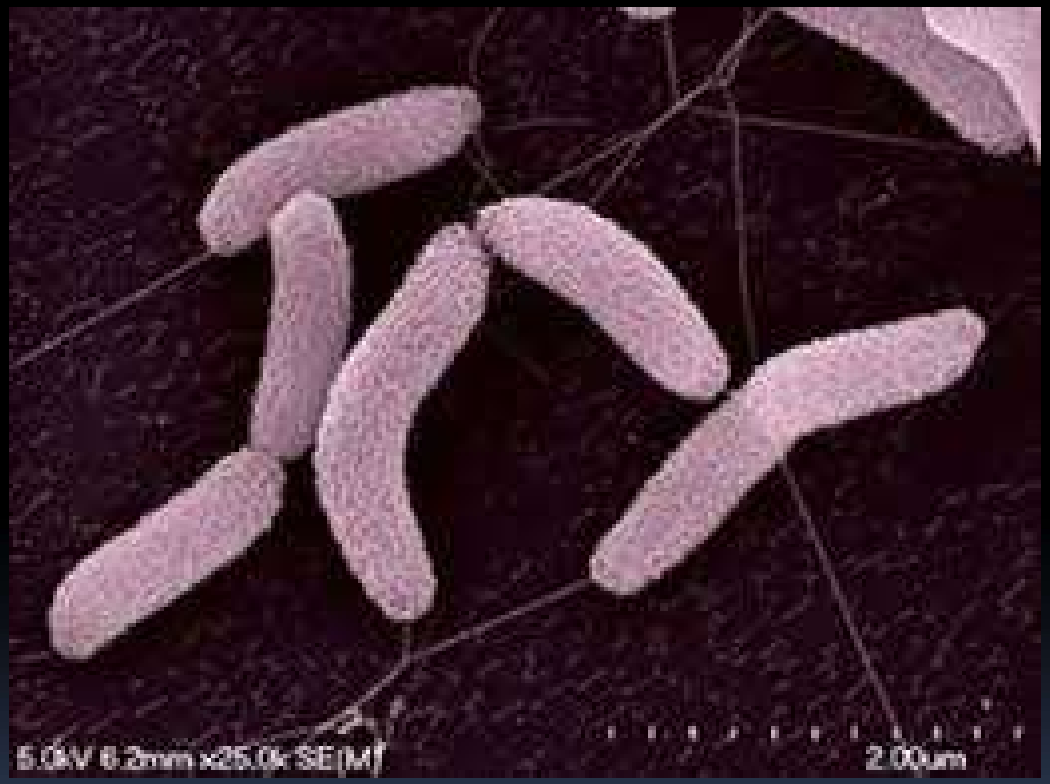
Sulphur reducers



- True anaerobes
- Undesirable
- Convert sulphur compounds to hydrogen sulphide
  - Highly acidic
- Indicator of waterlogged soils
- Reduce productivity

Transition to SOIL HEALTH

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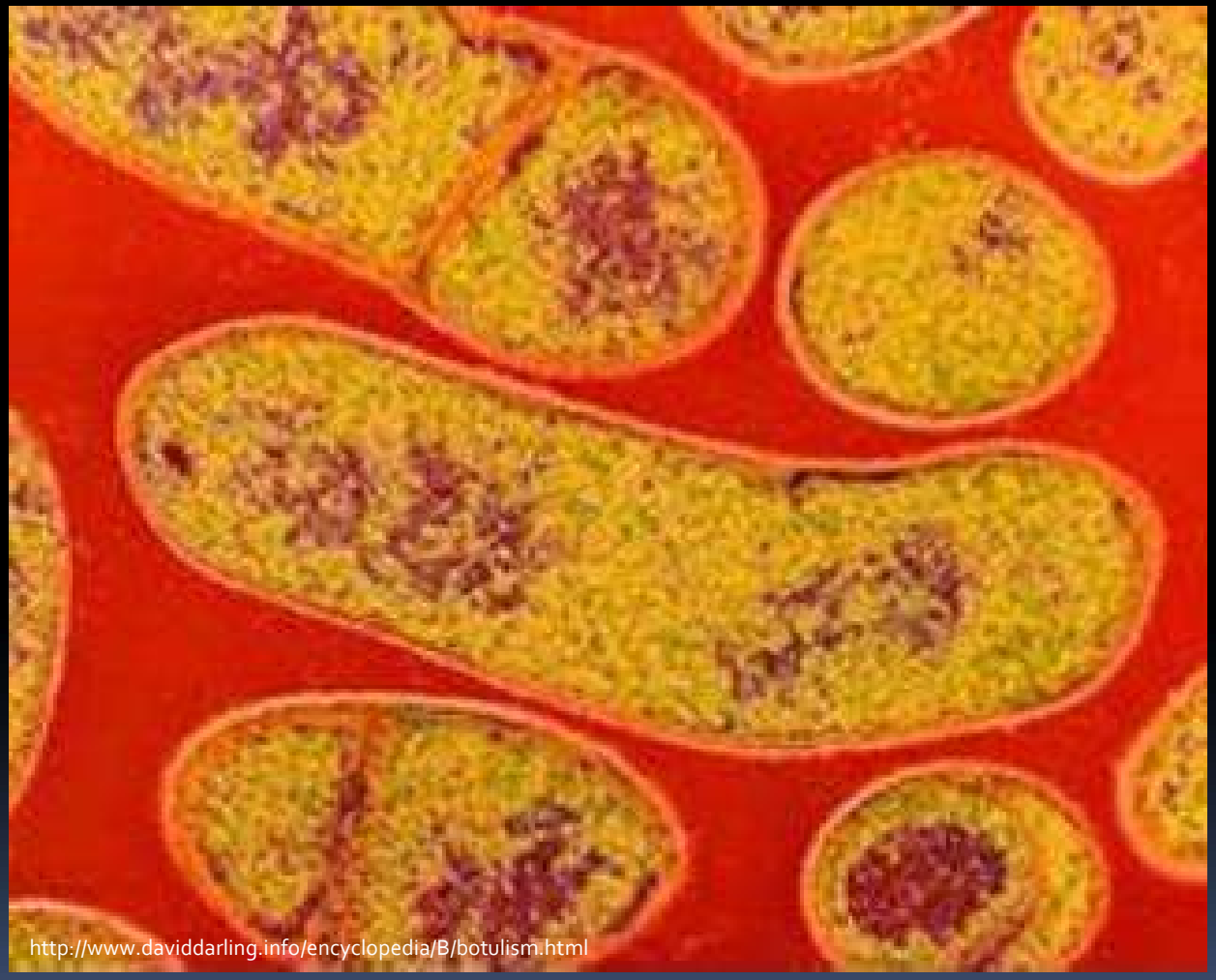
Anaerobic bacteria



Clostridium botulinum

- Produce plant-toxic compounds
- Damage roots
- Disease entry points
- Grow in waterlogged soils

Transition to SOIL HEALTH

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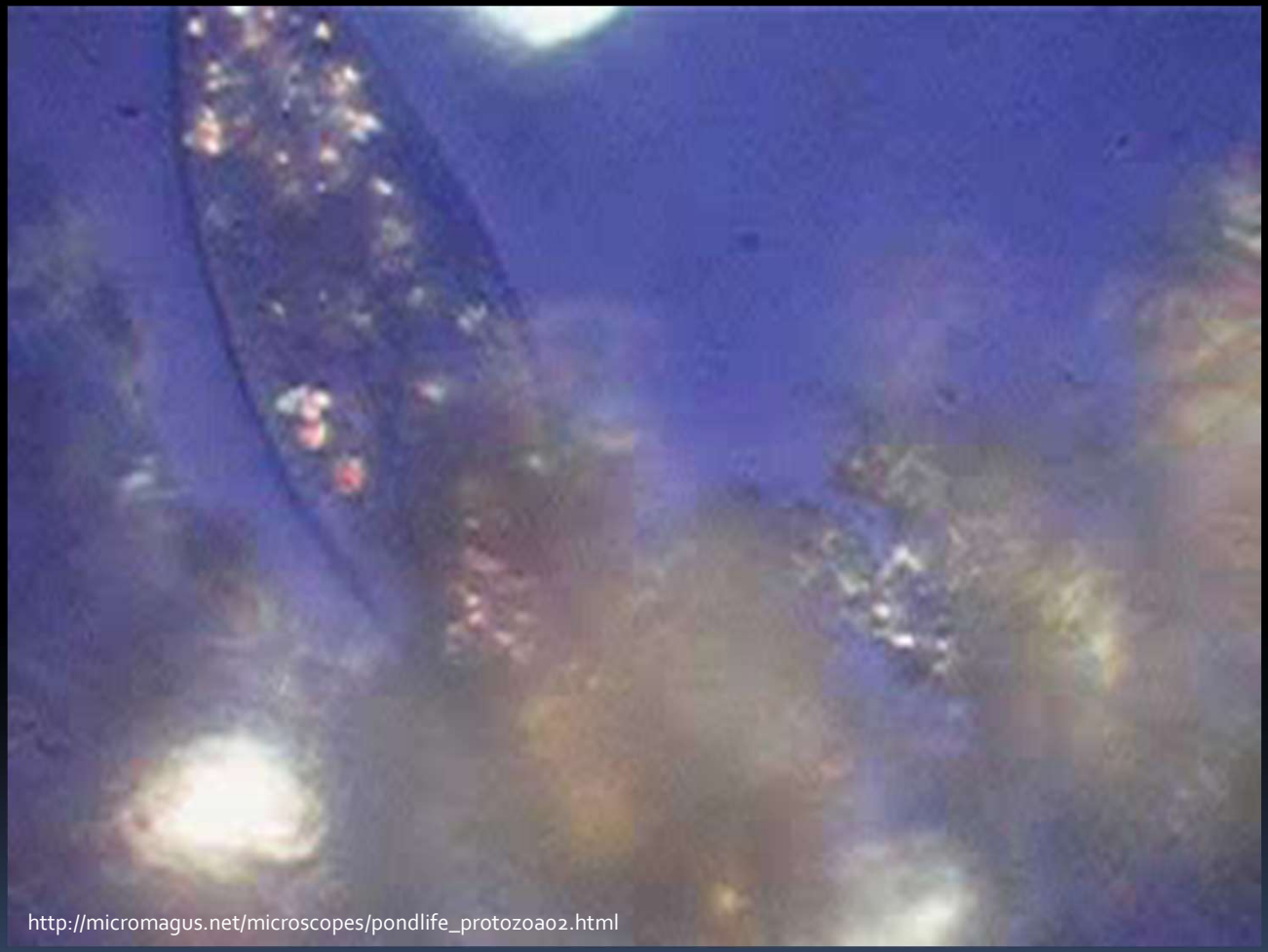
Protozoa



Paramecium sp.

- Feed off bacteria
- Cycle nutrients (N)
- Some can protect bacteria
- Indicate mature microbe system
- Sensitive to agrochemicals (herbicides)

Transition to SOIL HEALTH

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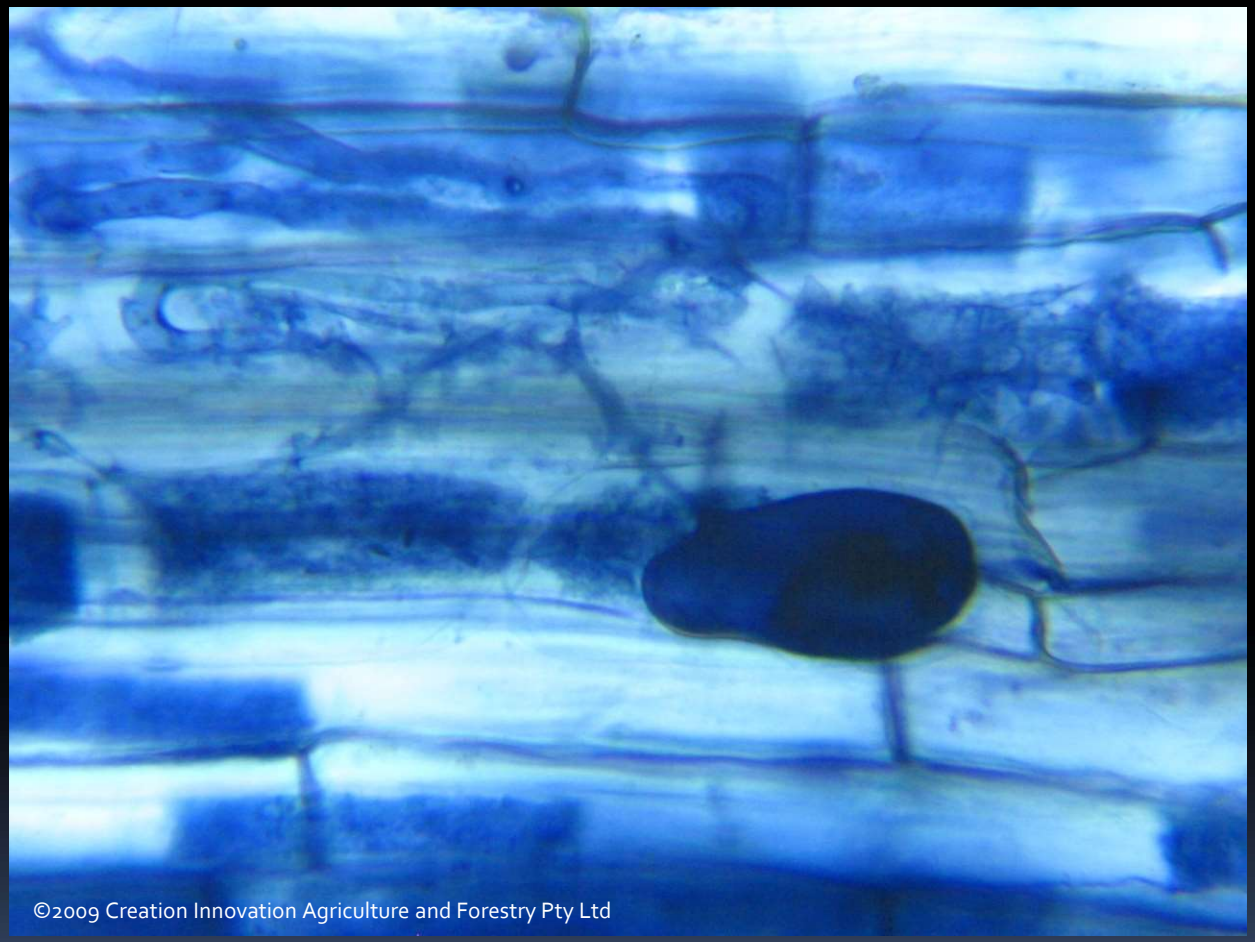
Mycorrhizal fungi



Arbuscular mycorrhizas (VAM) inside a plant root

- Transport nutrients to plants
- Increase dependent crop growth >80%
- Transport moisture
- Protect against disease

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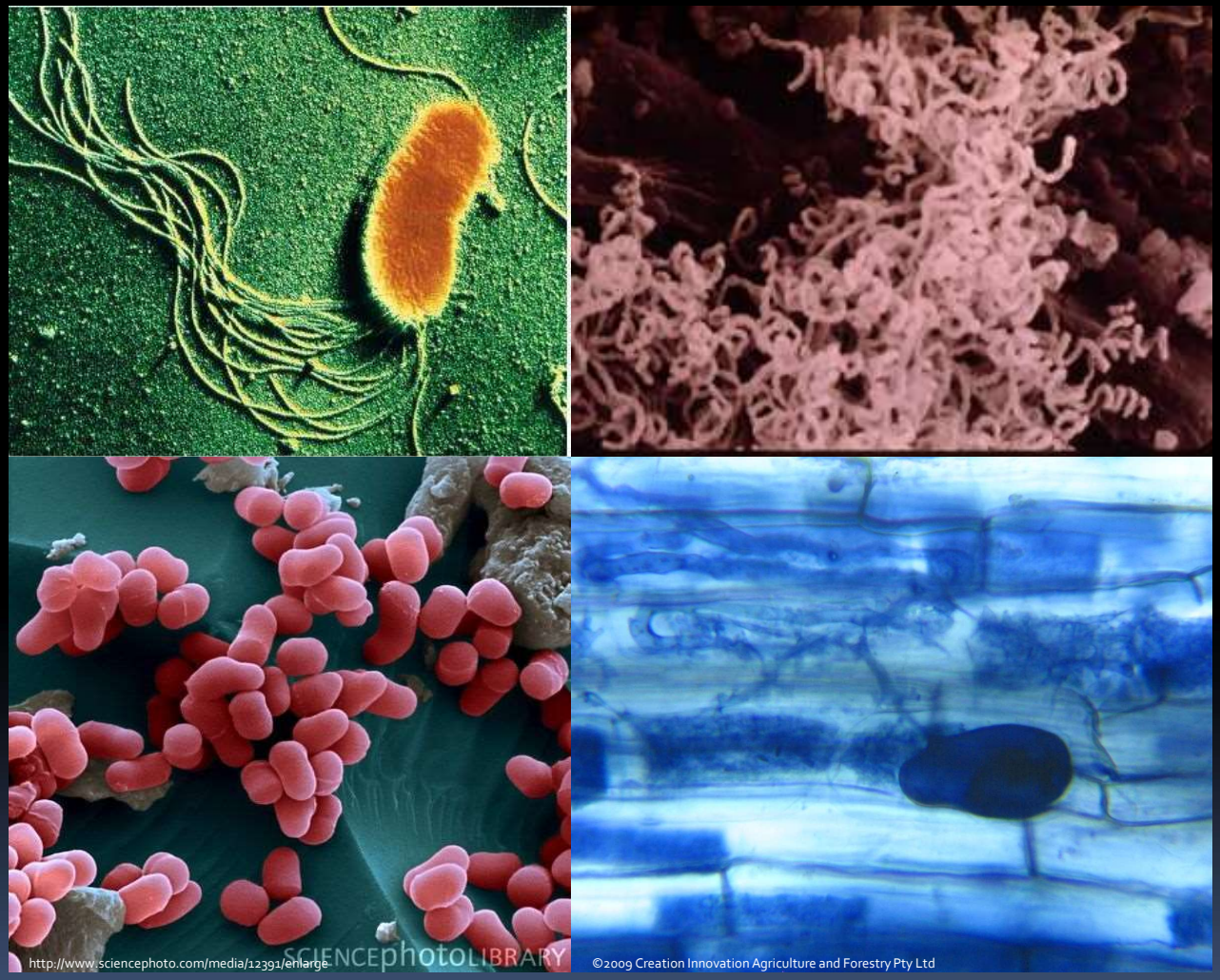
Transition to SOIL HEALTH

Microbial Diversity



- Diversity is good!
- Resilience
- Adapts to changing conditions
- Balance

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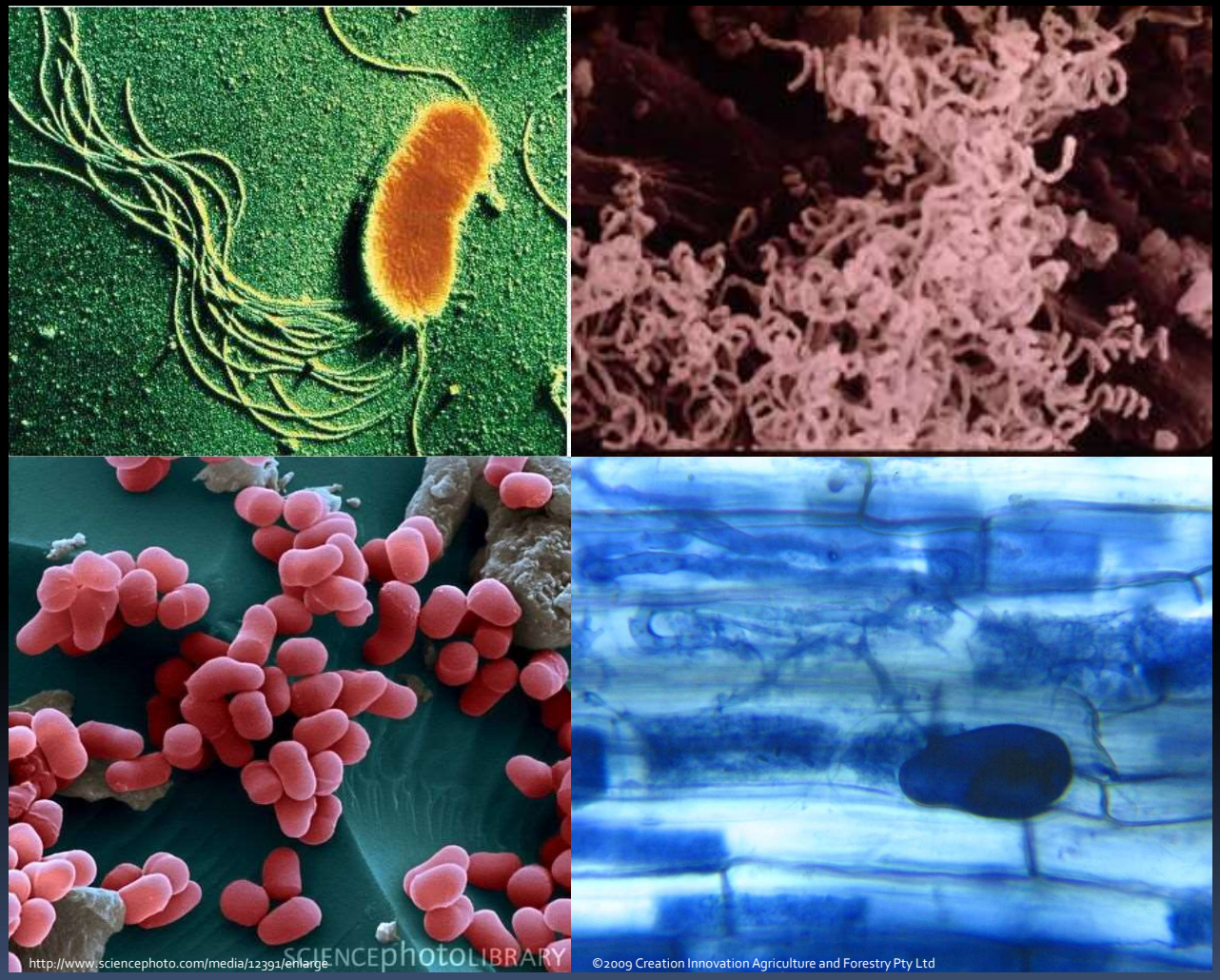
Fungi:Bacteria



- Fungi to Bacteria ratio related to
  - Food source/ Residue type (Rousk *et al.* 2007)
  - Soil pH (Baath & Anderson 2003)
  - Soil carbon (Nadezhda *et al.* 2015)
  - Measurement method (Baath & Anderson 2003)

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