THE UNIVERSITY OF WESTERN AUSTRALIA

Newcastle University

FACULTY OF SCIENCE

Soil health and related eco-system services in organic agriculture

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- Rural Research and Development Corporation
  - Australian Government

Overview

1. Soil biological diversity

2. Bio-physical / bio-chemical contributions
   Interactions between bio-physical / bio-chemical processes

3. Certification requirements define nutrient inputs
   - poorly soluble mineral nutrients - example

4.

5.

6.

Overview

1. Soil biological diversity

2. Bio-physical / bio-chemical contributions
   Interactions between bio-physical / bio-chemical processes

3. Certification requirements define nutrient inputs
   - poorly soluble mineral nutrients - example

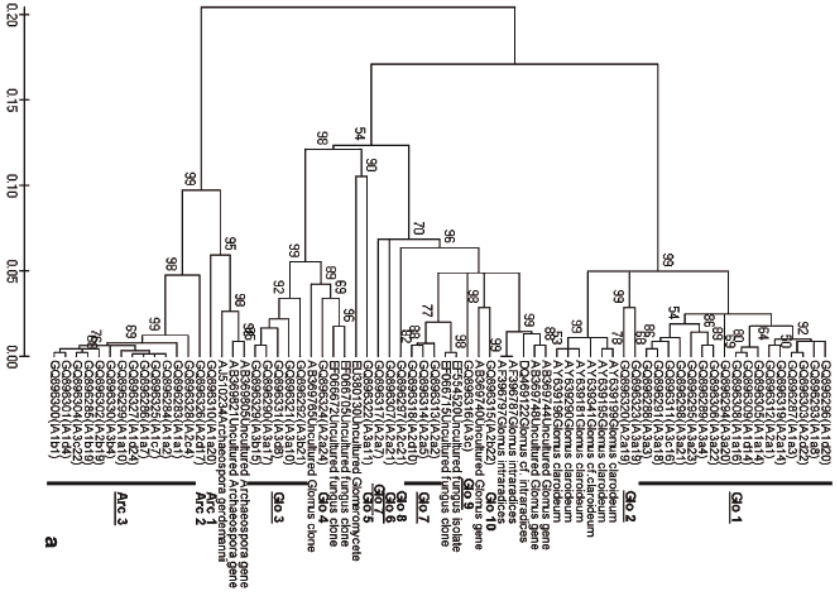
4. Effective use of organic resources (carbon)
   - piggery manure - example

5. Relevance of new insights into organic matter degradation

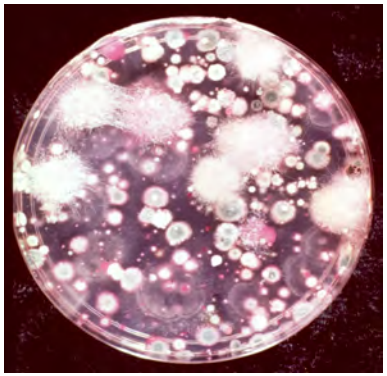
6. Organic agriculture as a model:
   - tackling the difficult question of maximising soil biological processes in agriculture for delivery of ecosystem services

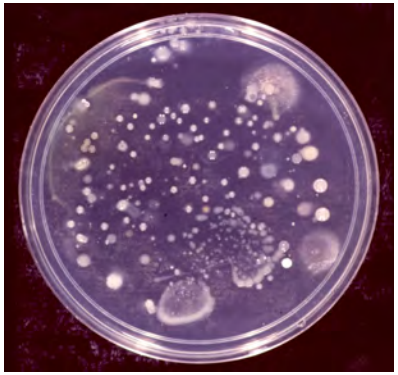
1. Soil biological diversity

How can its function be maximised in organic farming systems?



Soil biological diversity





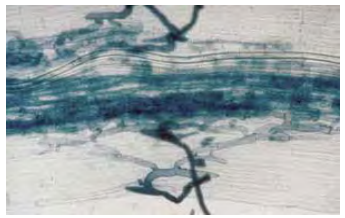
Soil microorganisms and fauna form extremely diverse and dynamic communities

They contribute, over different time frames, to:

- transformation of geological minerals
- release of essential nutrients for plant growth

Soils differ in widely their potential.

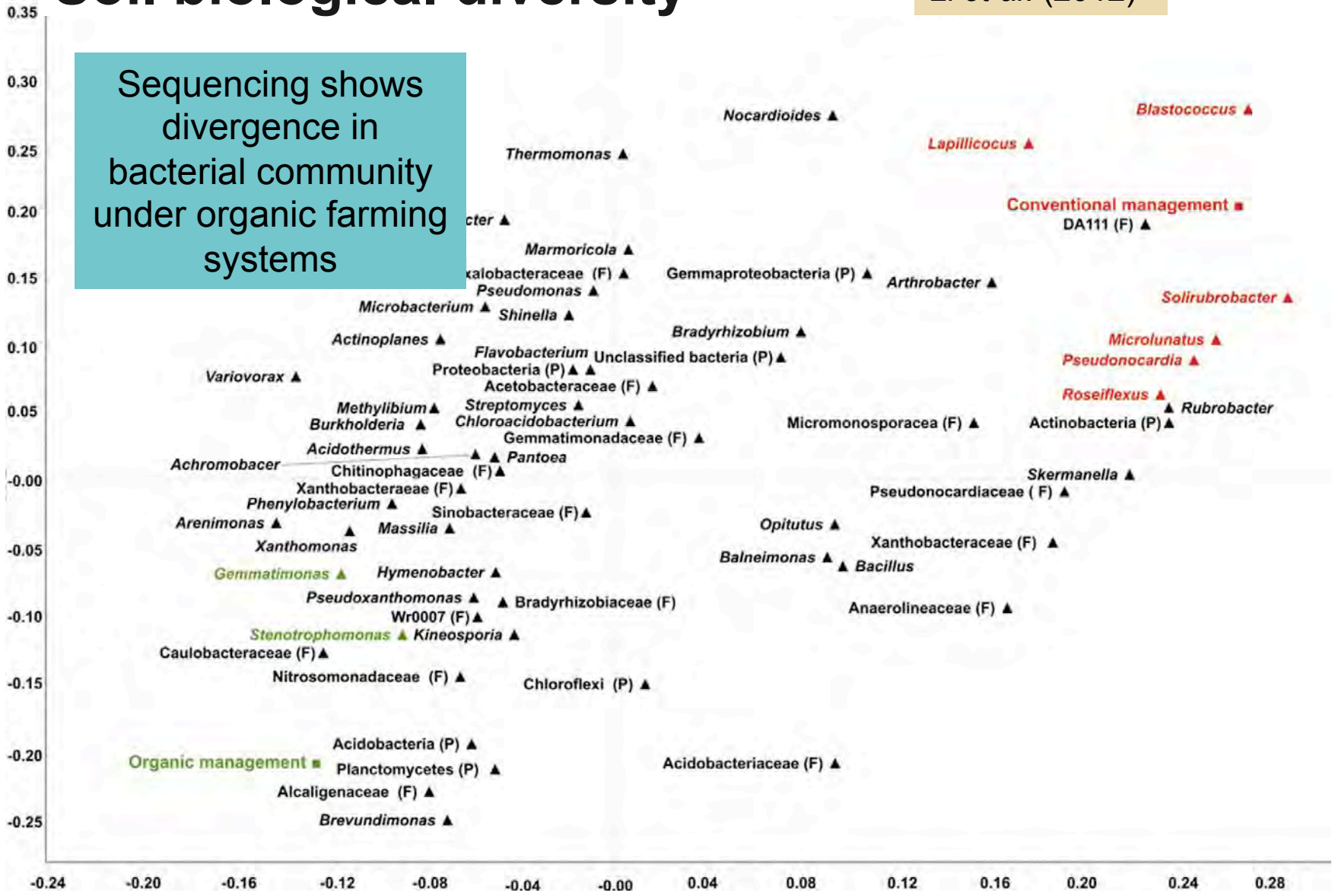
What are we aiming at? Local knowledge is important.



Soil biological diversity

Li *et al*. (2012)

Sequencing shows divergence in bacterial community under organic farming systems



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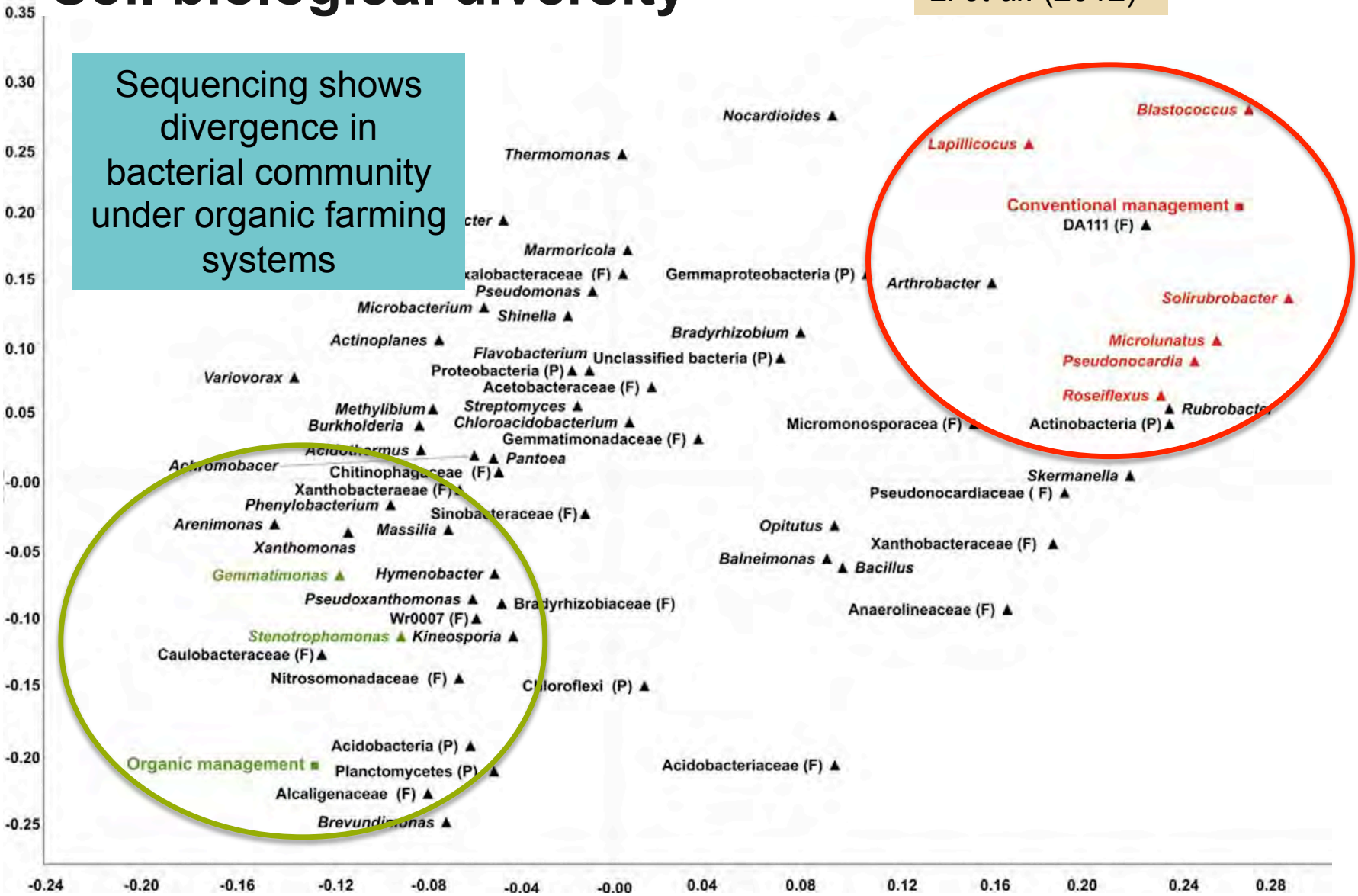

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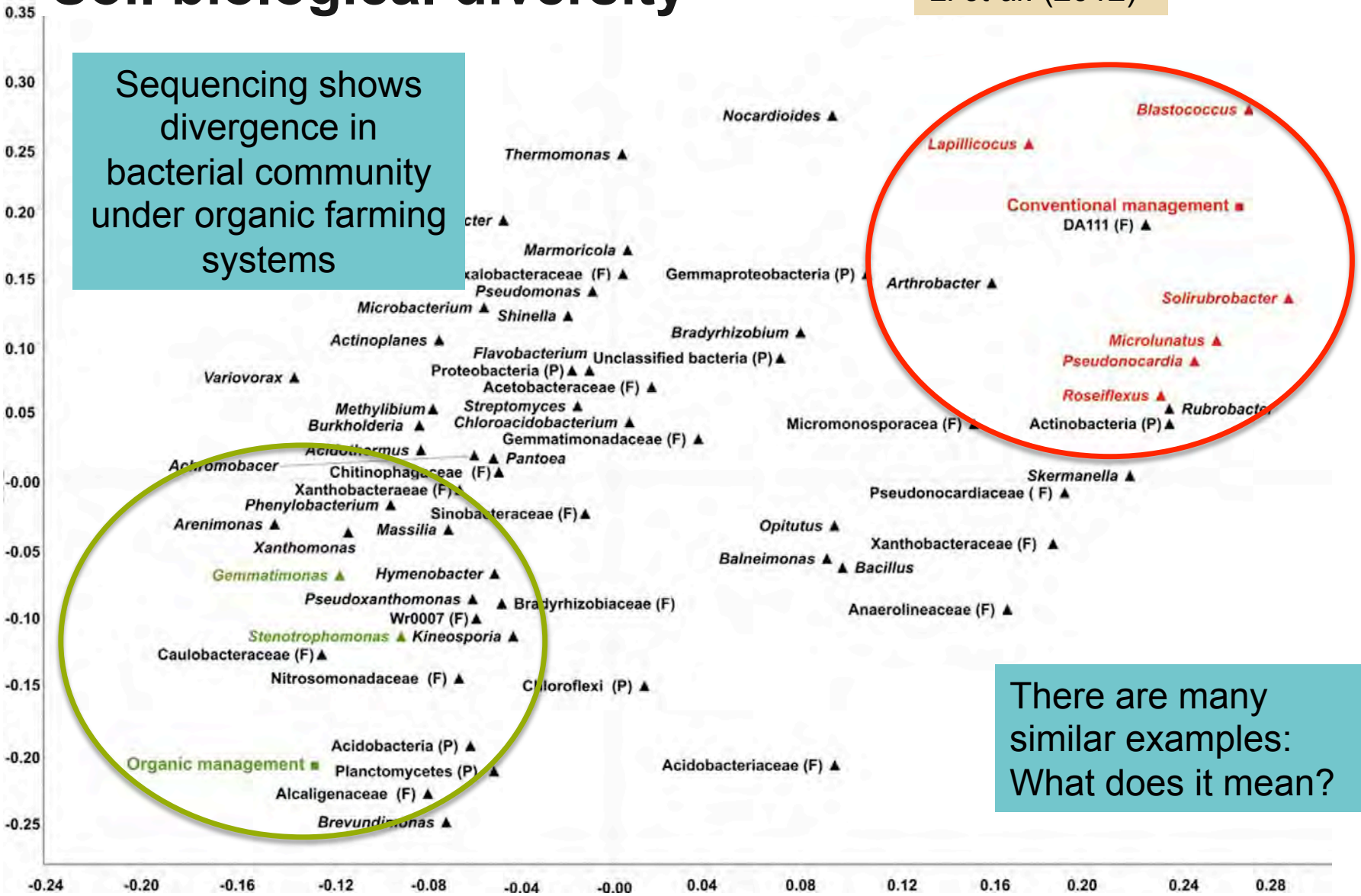


There are many similar examples: What does it mean?

Soil biological diversity

Can the **diversity and abundance** of soil microbial communities be altered specifically or generally to meet the needs of organic production?

What is the **target community**?

Does the target community change with time?

Do **indicator species need to be present** for best function?

What do these species indicate?

How abundant do they need to be to contribute to soil health?

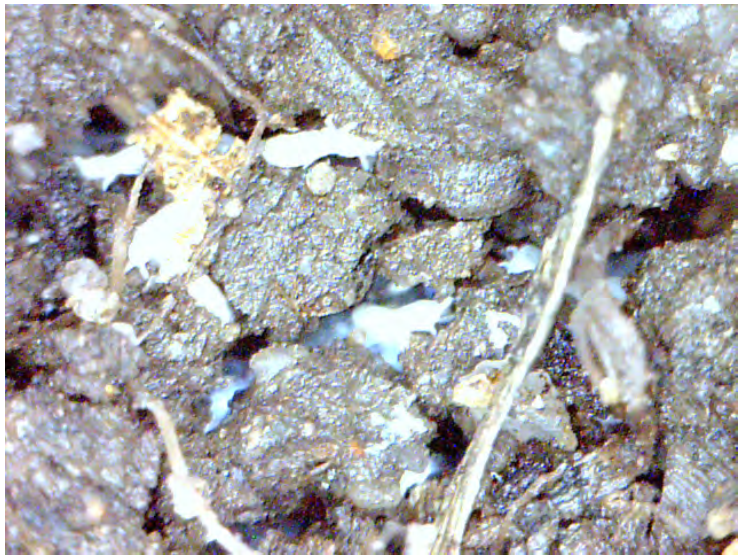
Local knowledge of soil and production practices is essential

2. Bio-physical / bio-chemical contributions

Interactions between bio-physical and bio-chemical processes

Soil health is dependent upon complex bio-physical and bio-chemical processes

All of these processes are **dynamic** and their relative importance changes spatially and temporally.



For organic agriculture, the challenge is to **fully capture** these benefits i.e. maximise the contributions of soil organisms.

Bio-physical processes (examples)

soil aggregation

e.g. protection of OM

e.g. role of fungal hyphae

mineral dissolution

e.g. release of nutrients from poorly soluble forms

biological perturbation

e.g. role of earthworms

water access / drought tolerance

e.g. role of mycorrhizal hyphae

Bio-chemical processes (examples)

mineralisation of organic matter

enzyme activity in the rhizosphere

nitrogen fixation
- symbiotic
- non-symbiotic

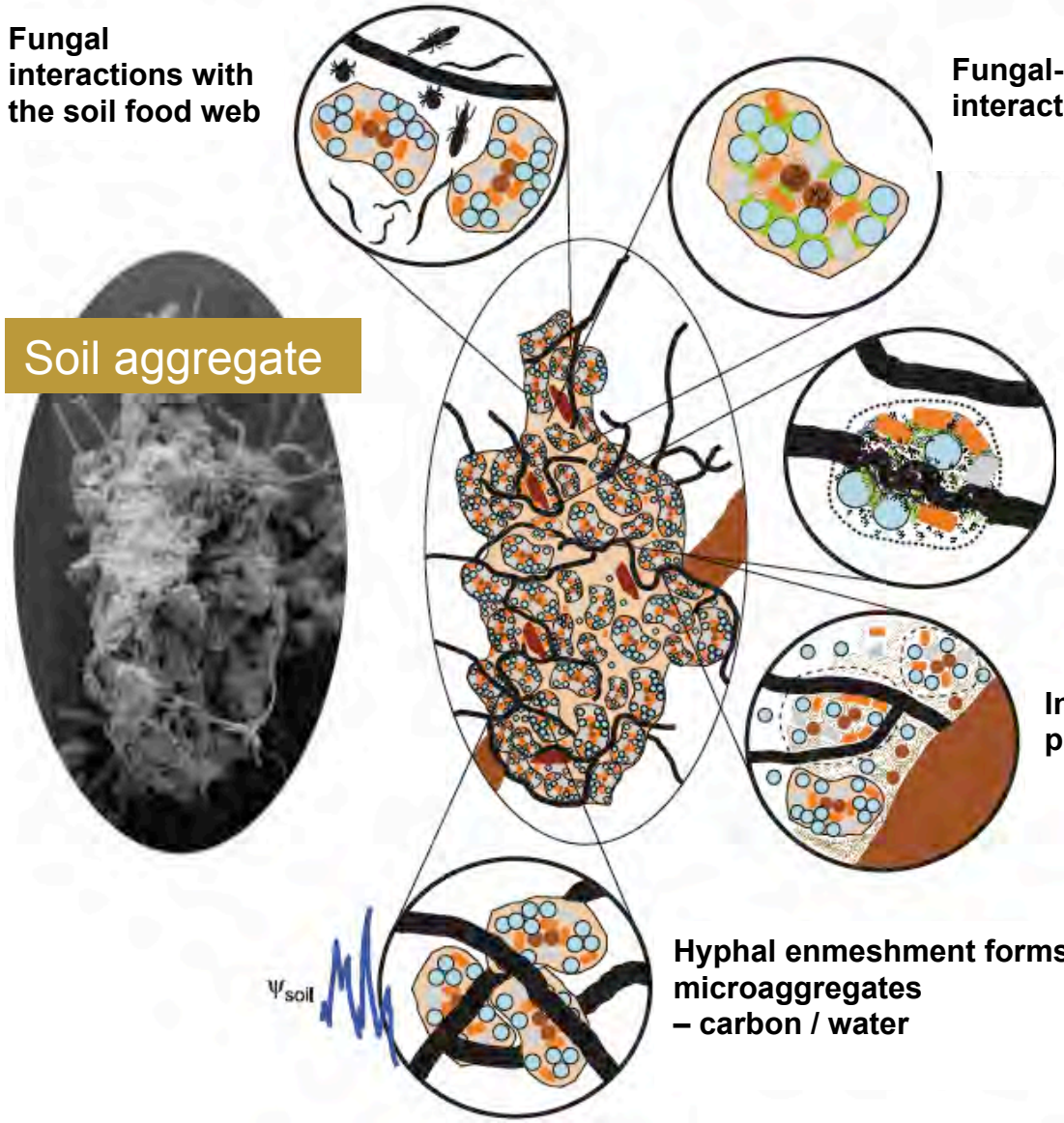
mycorrhizal associations - nutrient uptake

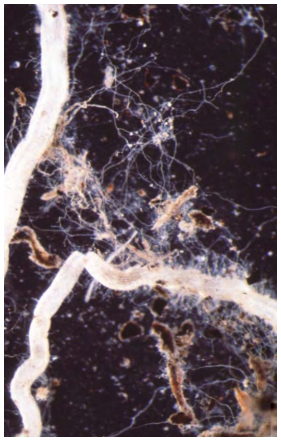
rhizosphere interactions
- nutrient uptake
- disease initiation / disease inhibition

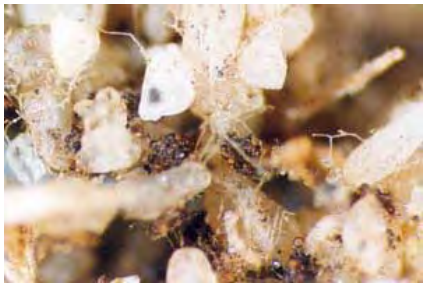
‘humus’ formation and nutrient transfers

Bio-physical and bio-chemical interactions

Rillig & Mummey (2006)





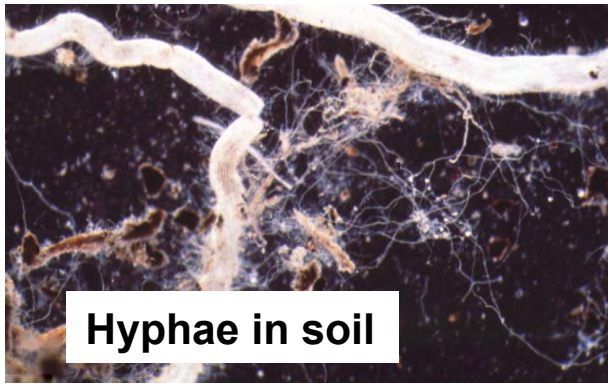


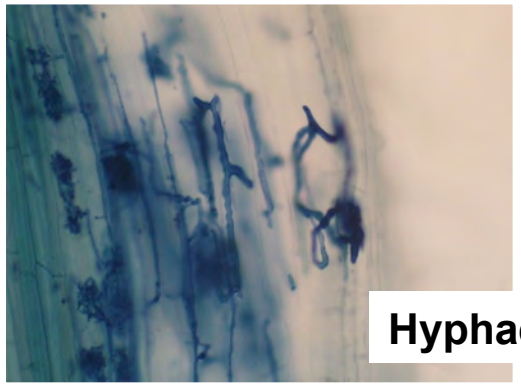
Bio-physical and bio-chemical interactions

Example: dynamics of arbuscular mycorrhizal fungi

- contribute to soil chemical **and** physical processes
- nutrient uptake / water uptake (when limited)
- interact with other organisms (e.g. collembola)

But it is difficult to identify the actual contributions because of the complexity of the interactions

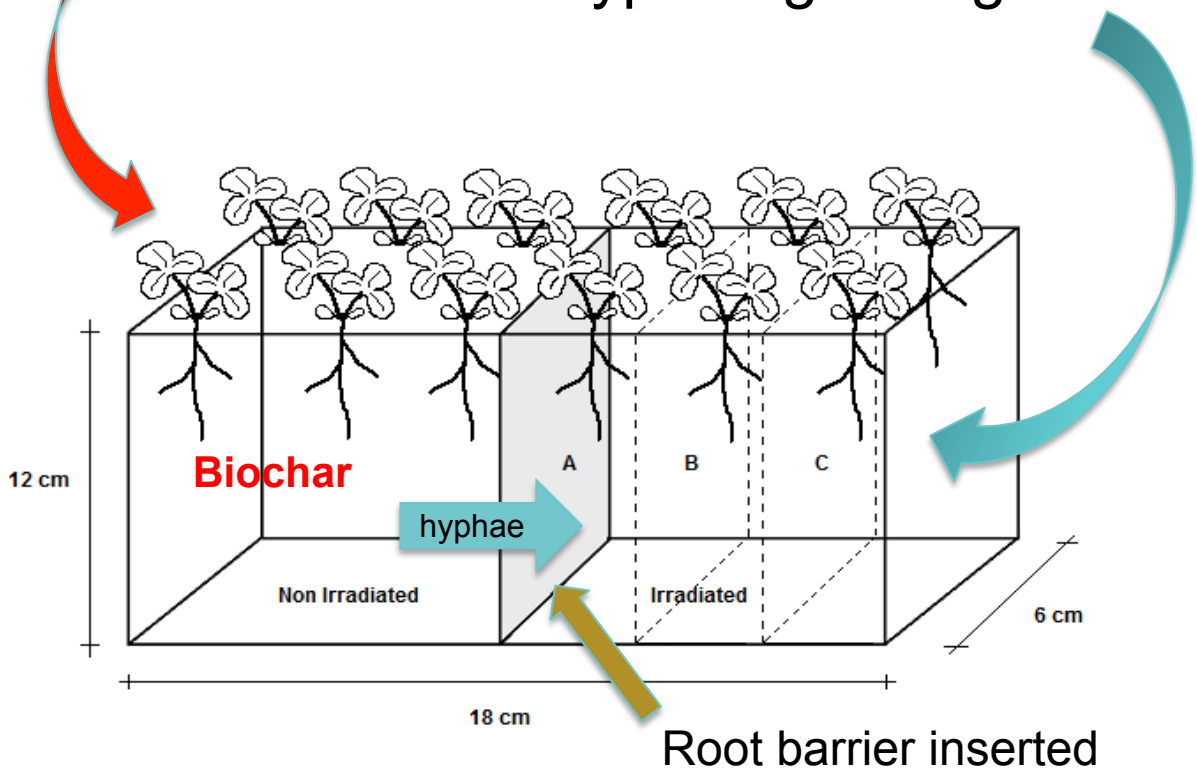




Bio-physical and bio-chemical interactions

Example of interactions with a soil amendment - biochar

- use a split chamber / **water limited**
- biochar added to left chamber
- measure hyphae growing into the right chamber



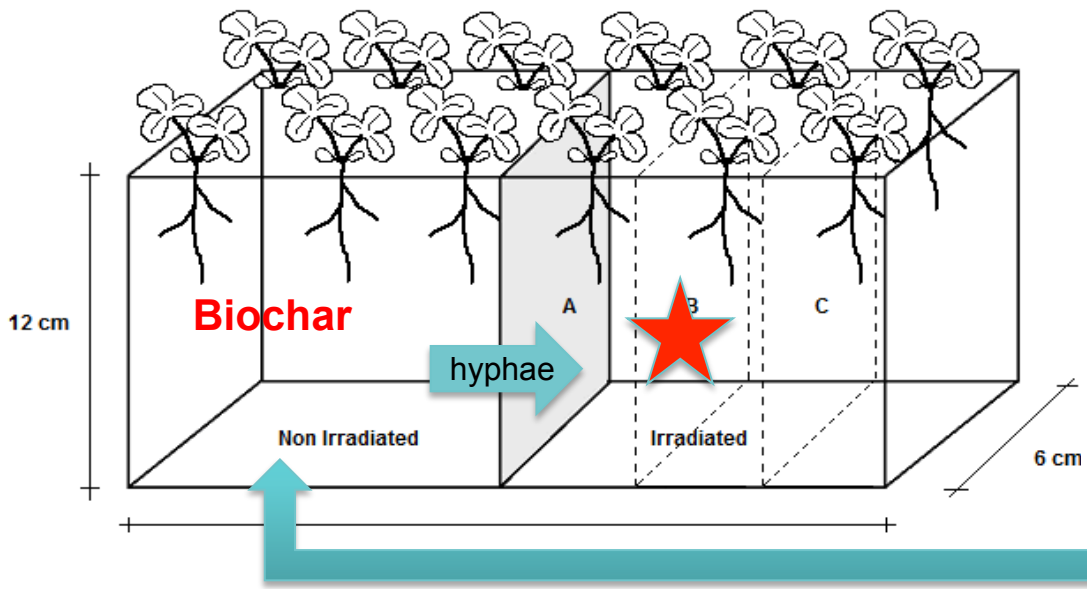
Mickan et al. (in prep)

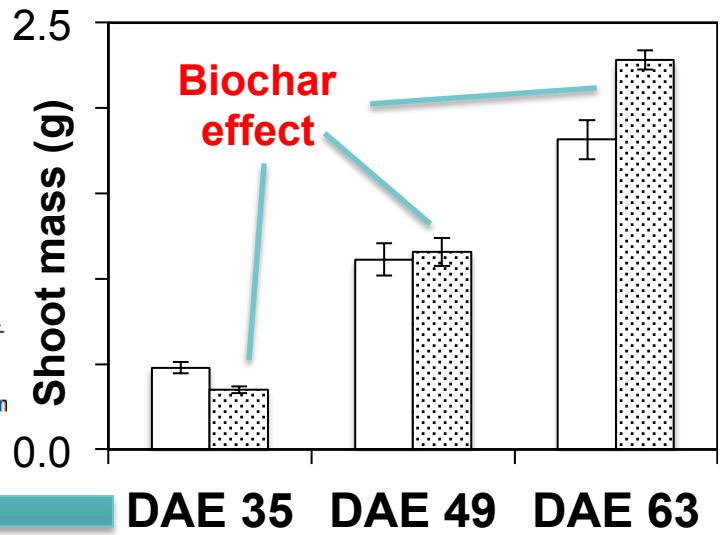
Bio-physical and bio-chemical interactions

Example of interactions with a soil amendment - biochar

- when **water limited**
- biochar added to left chamber
  decreased / increased plant growth
- effect was related to growth of mycorrhizal hyphae

Mickan et al. (in prep)





Bio-physical / bio-chemical contributions

Effective organic management should **maximise these processes**

Interdependence may be difficult to unravel

Understanding the processes should enable avoidance of detrimental soil management practices

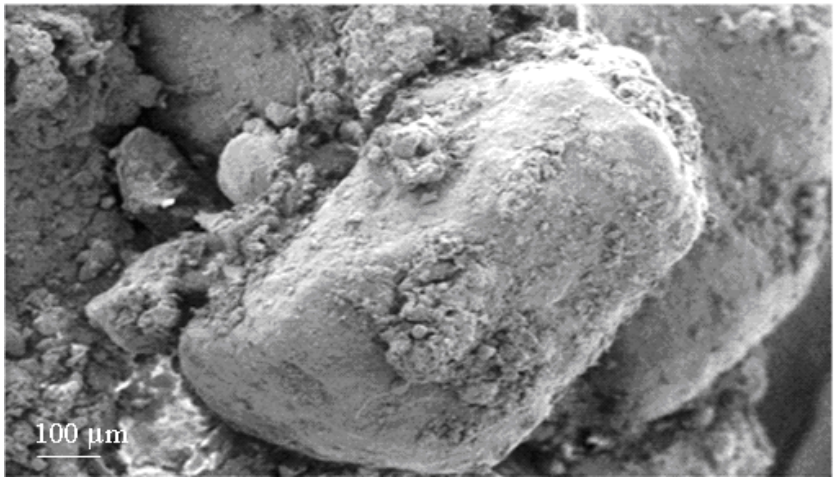
Soil tests may be inadequate to fully describe the state required

- they may differ from site to site
- they may be difficult to implement
- they may not be relevant

Local knowledge of soil and production practices is essential

3. Certification requirements define nutrient inputs

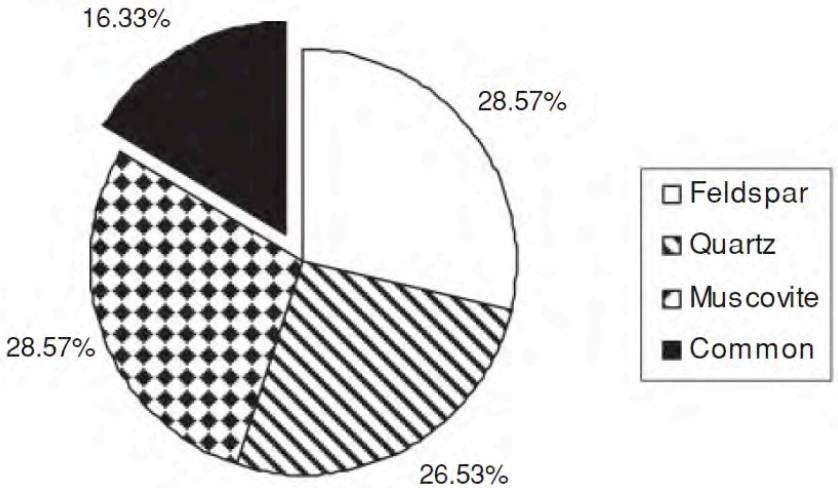
How do soil organisms interact with poorly soluble minerals?



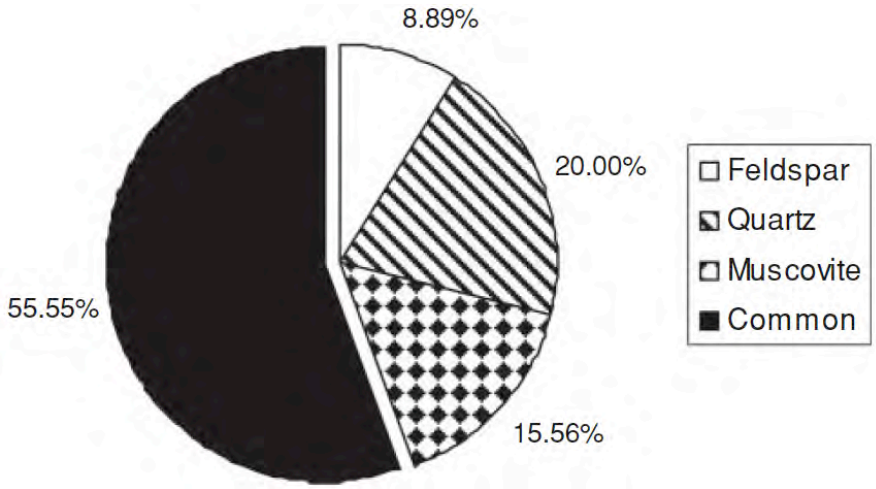
Interactions between mineral surfaces and microbial communities

Hutchens *et al*. (2010) "*Strong evidence was presented to conclude that community structure was indeed driven by the chemical composition of mineral substrates*."

Isolates of **bacteria** on mineral surfaces



Isolates of **fungi** on mineral surfaces

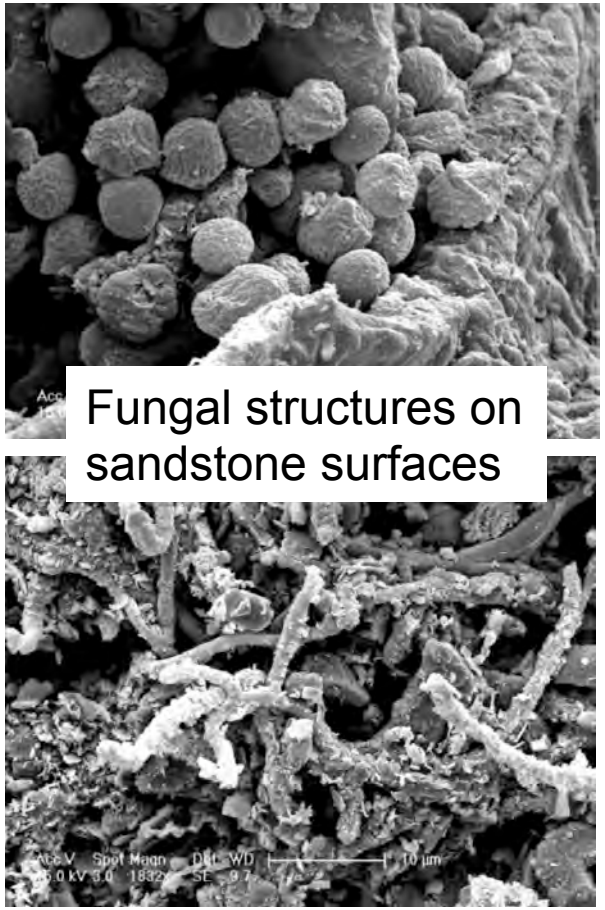


Potential for contribution to release of minerals and essential nutrients for plant growth

For **different mineral surfaces**, bacterial communities were generally more specific than fungi (Hutchens *et al*. 2010)

For **different sandstone surfaces**, differences in fungal diversity were less well defined - reflecting greater similarity in the surface environment (Gleeson *et al*. 2010)

Differences in microbial diversity reflect difference in habitat diversity



Fungal structures on sandstone surfaces

Gleeson *et al*. (2010)

Plant nutrients in minerals resources

X = structural element; T = trace

Harley & Gilkes (2000)

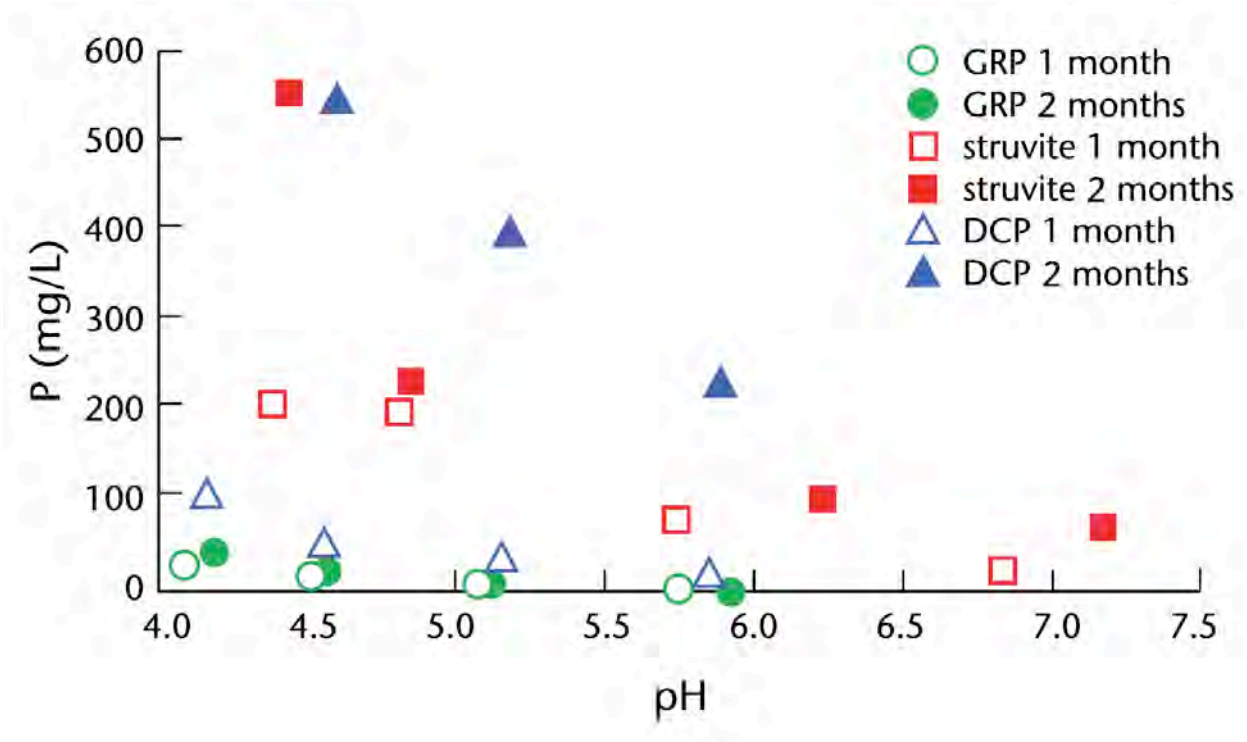
	K	Ca	Mg	P	S	B	Cl	Cu	Fe	Mn	Mo	Ni	Zn	Co	Na	Si
Quartz				T	T		T	T	T				T	T		X
								Feldspar Group								
K-feldspar	X			T	T		T	T	T	T			T	T		X
Plagioclase		X		T	T	T		T	T	T			T	T	X	X
								Feldspathoids								
Nepheline	X	T	T						T						X	X
Sodalite	T				T		X								X	X
								Mica group								
Muscovite/Sericite	X			T		C		T		T			T	T	T	X
Phlogopite (Mg:Fe>2:1)	X		X				T		X				T+			X
Biotite (Mg:Fe<2:1)	X		X	T	T	T	T	T	X	T+	C		T	T		X

Nutrients are available from poorly soluble forms (slow release)

What roles do soil organisms have in releasing them?

PHOSPHORUS: Solubility of sources

Manning (2008) after Ahmed (2005)

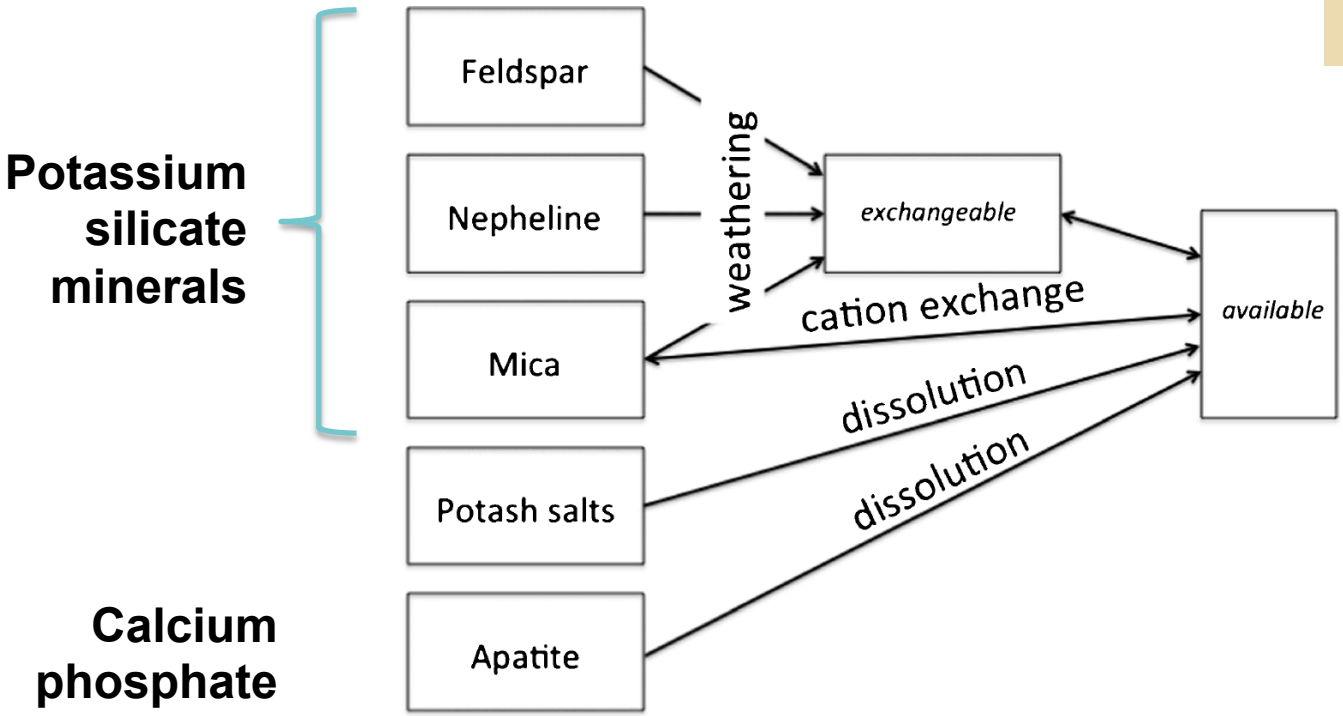


Variation in solubility of sparingly soluble phosphate sources in relation to pH.

GRP – Gafsar Rock P DCP = dicalcium phosphate

POTASSIUM: Processes controlling release

Manning (2012)



- **Potassium silicate minerals** release K following weathering to form K bearing clays /micas
- **Micas** can release K through cation exchange reactions as well as weathering

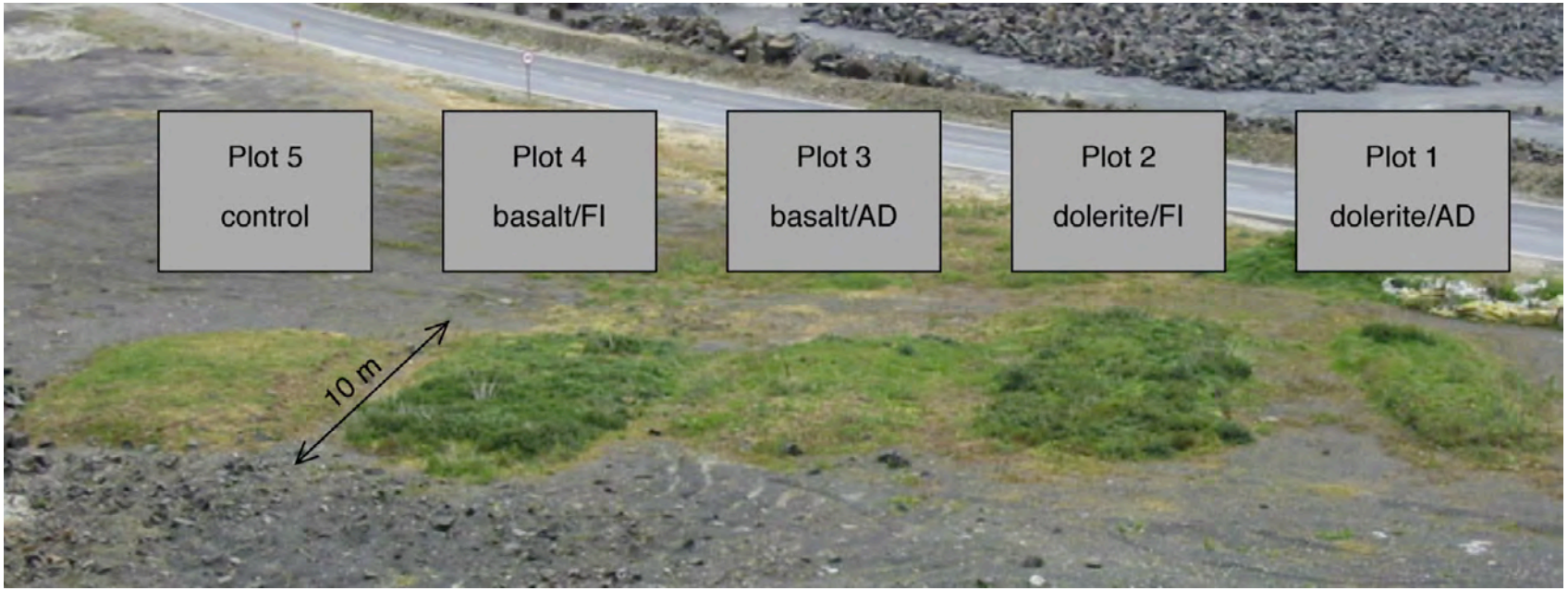
Rock dust – compost experiment

Manning *et al*. (2013)

Investigation of blends of **quarry fines and compost**

Plots 10m x 3m; trial established in 2003, sampled in 2007

AD = anaerobic digestate compost; **FI =** food industry compost



Certification requirements define nutrient inputs

Increasing diversity of mineral inputs

- this should increase microbial diversity

But this is not enough

- need to increase the abundance of key groups
- need to increase the activity of key groups

Understand the **synergistic interactions** between organic resources and mineral inputs

Local knowledge of soil and production practices is essential

4. Effective use of organic resources (carbon)

- e.g. piggery manure

Effective use of nutrients from animal wastes

Jenkins *et al*. (in prep)

Covered anaerobic ponds are stable and resilient to perturbation

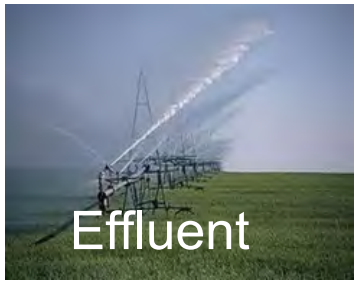
Breakdown of pig waste requires **4 microbial groups** to release biogas
- hydrolysers, fermenters, syntrophs and methanogens

Microbes need time to establish in the ponds (**monitor microbial profile**)

Biogas yield is related to microbial community structure (**monitor**)

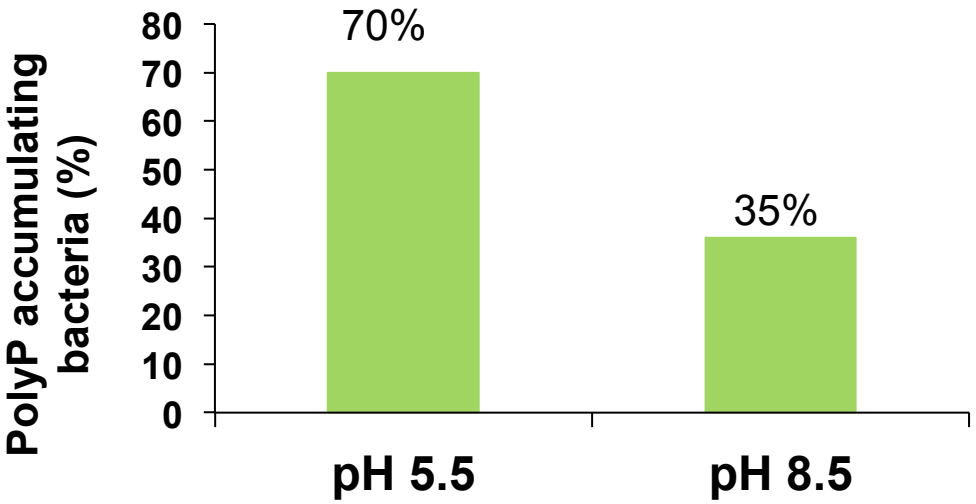
Seed established community (from 'organic' source – no antibiotics)

Effective use of nutrients from animal wastes



Composting solids from effluent ponds

Removing excess P using phosphate accumulating bacteria



Effectiveness of polyphosphate accumulation is related to pH

Weerasekara *et al*. (in prep)

Effective use of organic resources (carbon)

Systems are available to for **maximizing efficiency of use** of valuable animal ‘wastes’ in organic farming systems

Efficient **composting** processes have been developed using

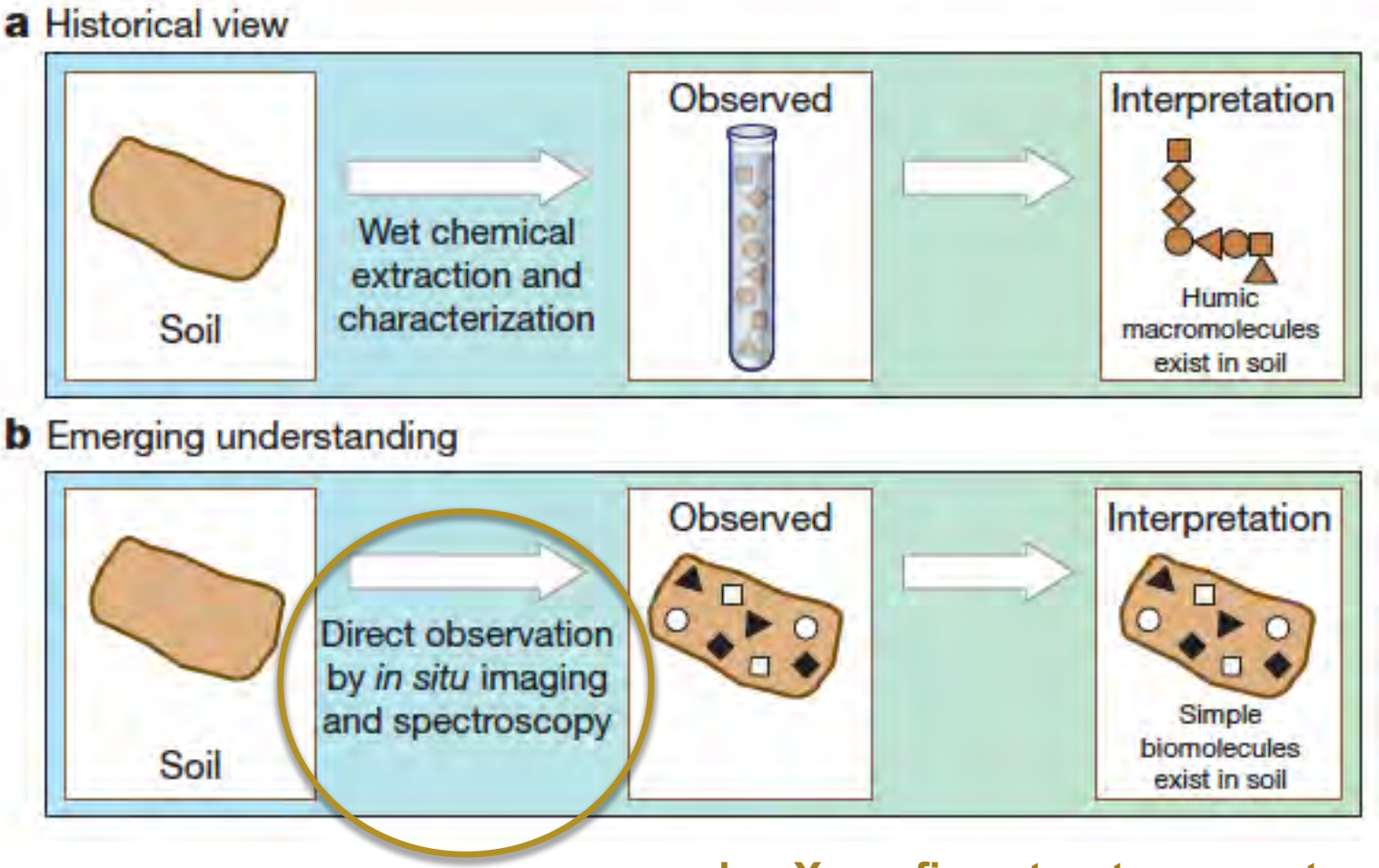
- defined sources of organic materials
- incorporation of clays, minerals

Microbial capture of P from organic ‘wastes’ needs implementation

Local knowledge of soil and production practices is essential

6. Relevance of new insights into organic matter degradation

New insights into organic matter degradation



Schmidt *et al*. (2011)

near-edge X-ray fine structure spectroscopy + scanning transmission X-ray microscopy

New insights into organic matter degradation

Dungait *et al*. (2012)

Stable isotope tracing is providing new quantitative information about the relationships between the N, P and C macronutrient cycles

High precision characterization of the multiple forms of N, P and C is becoming possible, improving the tracking of nutrients through the complex pools and processes in soils

Clearer understanding of the **scale and spatial organisation** of physico-chemical reactions with biological processes is emerging

When applied to organic systems, **responses to climate change** will be easier to predict

Local knowledge of soil and production practices is essential

7. Organic agriculture as a conceptual model for other farming systems

- tackling the difficult question of maximising soil biological processes in agriculture

Organic agriculture as a conceptual model for other farming systems

Emphasis on **farm nutrient budgets**

Emphasis on **efficient use of nutrients** (actually constrained compared with open ended N-driven systems)

Emphasis on **P cycles as well as N/C cycles**

Emphasis on **use of biological processes** for nutrient provision and disease control

- soil biological processes can be overridden in other systems
  - reducing efficiency in P uptake by plants
  - reducing nitrogen fixation (symbiotic and non-symbiotic)

Local knowledge of soil and production practices is essential

Summary

1. Soil biological diversity

2. Biophysical / biochemical contributions and their interactions

3. Certification requirements define nutrient inputs
   - solutions for poorly soluble mineral nutrients

4. Effective use of organic resources (carbon)
   - piggery manure – example

5. Relevance of new insights into organic matter degradation

6. Organic agriculture as a model:
   - tackling the difficult question of maximising soil biological processes in agriculture for delivery of ecosystem services

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