Measuring and monitoring SOIL BIOLOGY **Biological indicators** of SOIL HEALTH **Soil management** and SOIL CARBON

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Soils Matters Workshop: Margaret River Wine Association August 2021

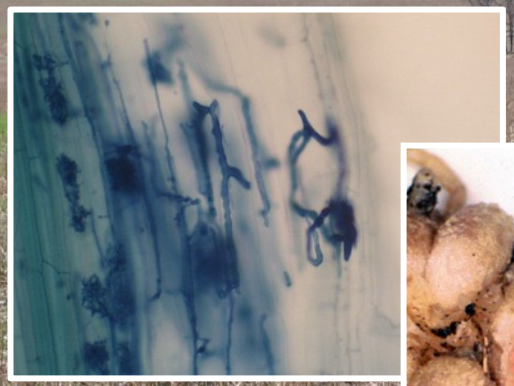
Acknowledgements

Dr Sasha Jenkins
Dr Mark Farrell
Dr Bede Mickan
Dr Zakaria Solaiman
Ian Waite
Dr Anjani Weerasekara,
Dr Noraini Jaafar
Dr Sanjutha Shanmugam
Dr Peter Mawson
Tuo Deng
Bernice Addo

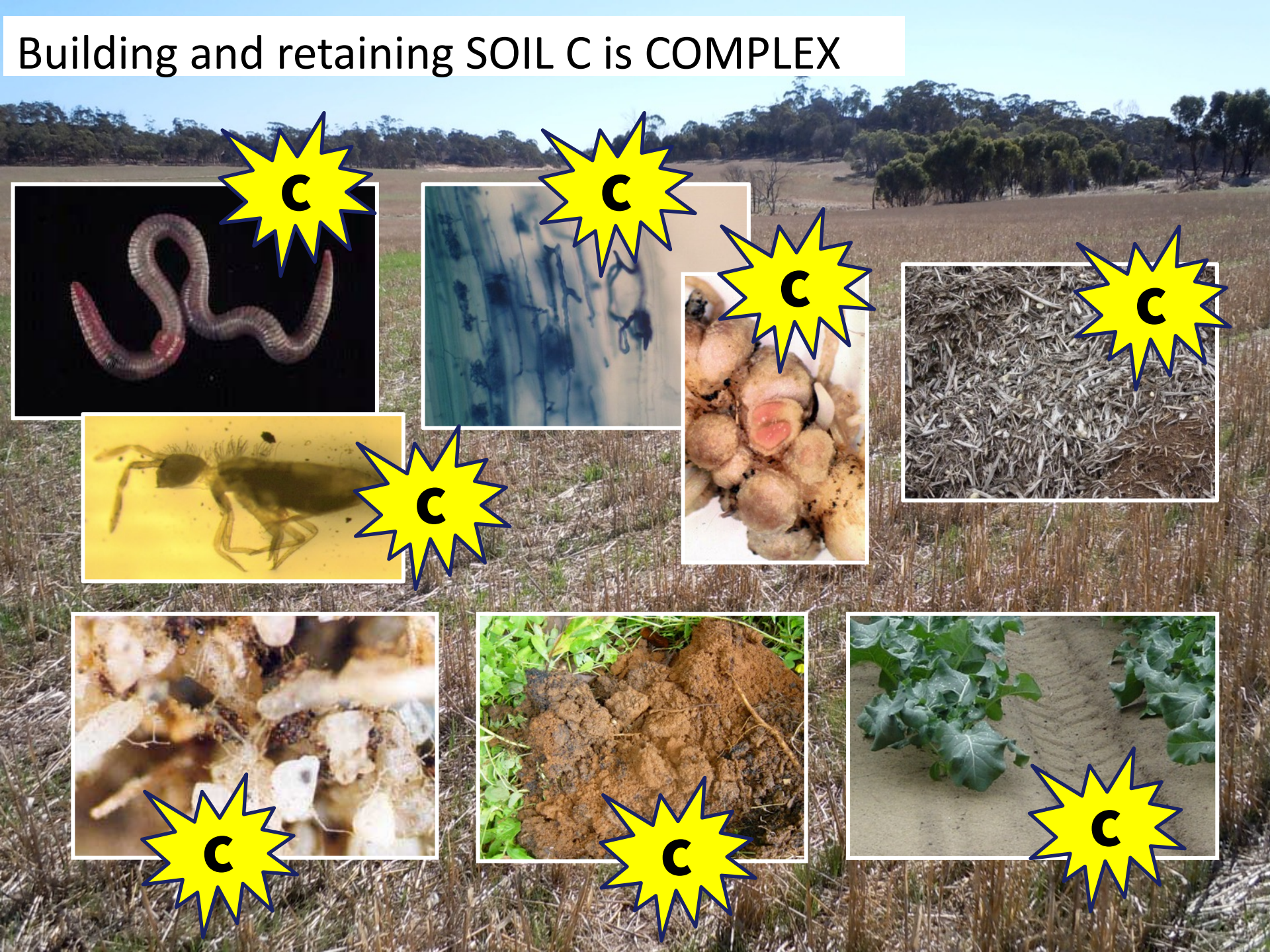
Overview

1. Principles of soil biological fertility
   - nutrient placement, scheduling of nutrients
   - soil C sequestration, time required for changes
2. Options available for managing soil C?
3. Measuring and monitoring (what, when?)
4. What do the assessments ‘indicate’?
5. SOIL ACTION PLAN

Soil biological fertility is complex



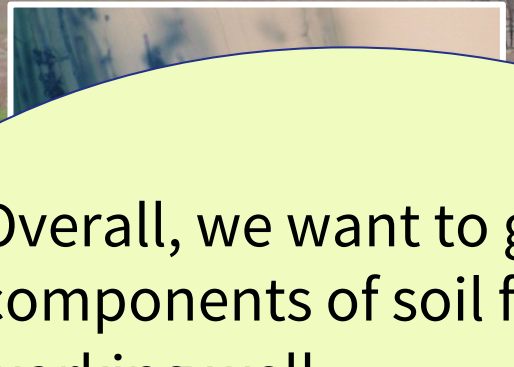
Building and retaining SOIL C is COMPLEX



What is in soil and what does it do?

- Soil Health Animation 1

Building and retaining SOIL C is COMPLEX



Overall, we want to get all components of soil fertility working well

but the emphasis is usually on soil physical and chemical processes….

‘Indicators’ of soil health

Indicator – implies PREDICTION

Measurement – requires CONTEXT

… a few principles related to…

Soil biological fertility

- time → Biological processes establish gradually
- nutrient replacement → Nutrients lost need to be replaced
- scheduling of nutrient supply → Nutrients will be supplied gradually

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Soil biological fertility…

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Implications for…

- plant physiology → How does slow nutrient release influence the plant? productivity?
- product quality
  - grain
  - forage → Does slow nutrient release influence grain or forage quality?
- costs / profitability → Is cost reduced? Is profitability increased?

Principles of Soil Biological Fertility

1	Soil organisms are most abundant in the surface layers of soil
2	Soil organic matter is necessary for nutrient cycling and soil aggregation
3	Soil biological diversity is related to diversity of organic matter and habitats
4	Nitrogen-fixing bacteria form specific associations with legumes
5	Nutrients released during organic matter breakdown enter soil and the soil microbial biomass
6	Arbuscular mycorrhizal fungi can contribute to P use efficiency and soil conditions (including C sequestration)
7	Soil amendments alter the physical and chemical environment of soil organisms
8	Some crop rotations and tillage practices decrease the suitability of soil for plant pathogens
9	Production systems based on soil biological fertility can be profitable
10	Soil biological processes develop slowly

Soil biological amendments*

* Extensive variation within amendment categories

Biological amendments
Humates / biochar etc
Manures / composts
Compost teas / biological extracts
Microbial inoculants

GRDC Project
Understanding Biological Farming Inputs

Mark Farrell (CSIRO)
Sasha Jenkins (UWA)

Lynne Macdonald (CSIRO)
Mike Webb (CSIRO)
Mike Wong (CSIRO, now Murdoch)

Review:
Abbott et al. (2018)

Abbott LK, Macdonald LM, Wong MTF, Webb MJ, Jenkins SN, Farrell M (2018) Potential roles of biological amendments for profitable grain production – A review. *Agriculture, Ecosystems and Environment* 256: 34-50

… biological amendments to address soil biology (carbon driven)

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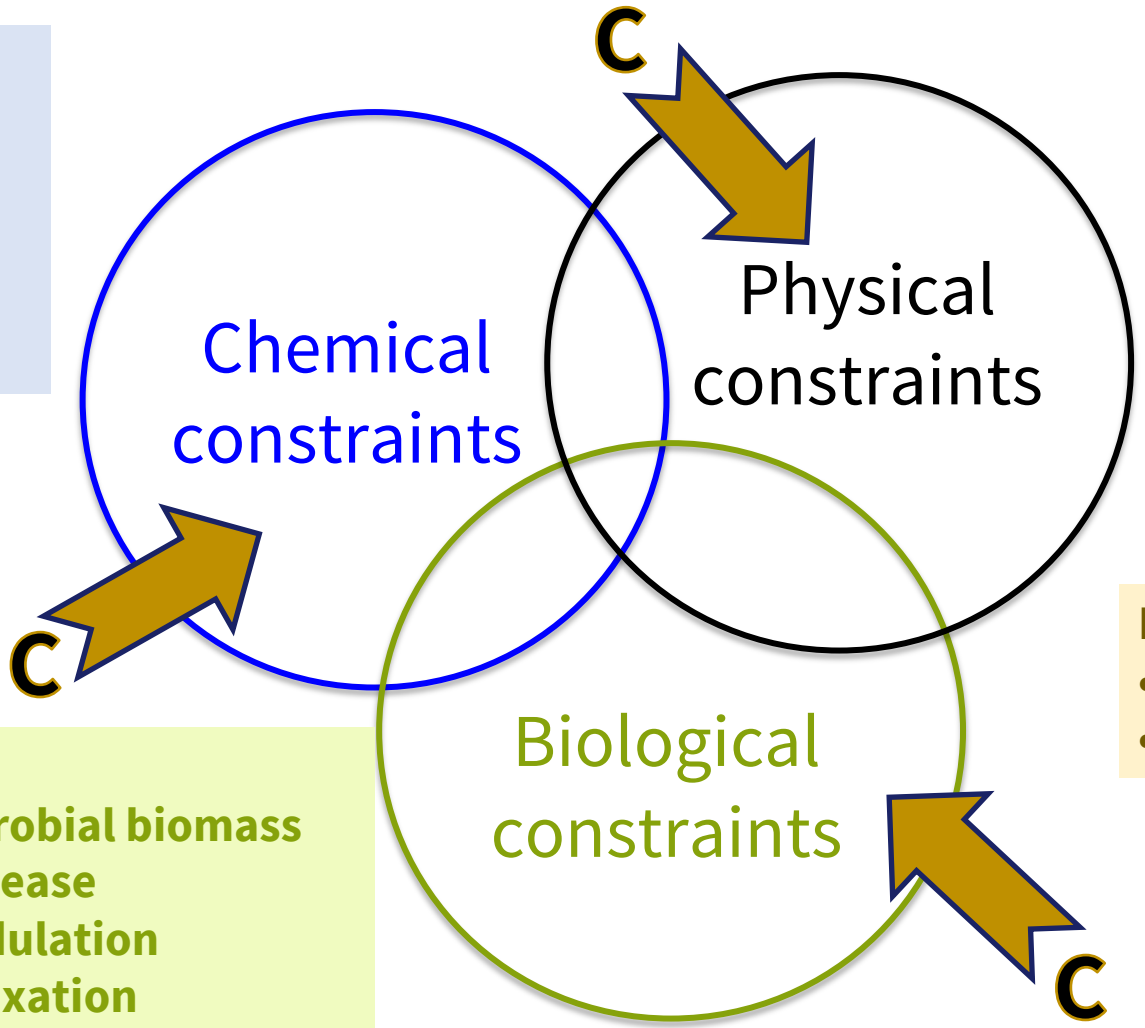
- Salinity
- Low C
- Low N
- Low pH
- High pH
- Low CEC



- Erosion
- Water retention
- Water infiltration
- Soil aggregation
- Compaction

PLANT:
- Drought (seasonal)
- Frost

SOIL:
- Low microbial biomass
- Plant disease
- Poor nodulation
- Low N_2 fixation
- Low levels of AM fungi

* Multiple impacts also likely

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Review:
Abbott et al. (2018)

Soil biological amendments

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CSIRO AGRICULTURE & FOOD
www.csiro.au

CSIRO

Biological amendments for the Australian grains industry: summary review and framework

LM Macdonald[1], LK Abbott[2], MFT Wong[1,3], MJ Webb[1], SN Jenkins[2], M Farrell[1].

A report to the Grains Research and Development Corporation

July 2018

https://grdc.com.au/resources-and-publications/groundcover/groundcover-137-november-december-2018/in-depth-look-at-biological-amendments

Use of soil Biology tests:

Soil testing for research purposes *vs* farm management

Immediate *vs* delayed analysis (**soil storage**)

- where do you send **biological samples**?

What does the soil test "**indicate**"?

Use of soil Biology tests:

Conceptual difficulties:

Definition of soil health/quality	**(biological fertility)**
Baselines	**(local knowledge is essential)**
Individual biological components	**(use 5-year concept)**
Response to management	**(monitoring)**

Practical difficulties:

Complex methodologies	**(be consistent)**
Temporal/spatial variation	**(chose appropriate sampling)**
Differences with soil types / climatic zones	**(local knowledge)**
Different requirements for farmers & researchers	**(this is OK)**

Soil Health Institute (USA) endorses 19 national soil health measurements

Specific Tier 1 measures endorsed include:

organic carbon,
pH,
water-stable aggregation,
crop yield,
texture,
penetration resistance,
cation exchange capacity,
electrical conductivity,
nitrogen,
phosphorus,
potassium,
carbon mineralization,
nitrogen mineralization,
erosion rating,
base saturation,
bulk density,
available water holding capacity,
infiltration rate, and
micronutrients

http://soilhealthinstitute.org/national-soil-health-measurements-accelerate-agricultural-transformation/

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Dr. Steven Shafer, Chief Scientific Officer with the Soil Health Institute said:

"…several biological measurements have significant potential to help suppress diseases naturally, improve water quality, build drought resilience, increase carbon sequestration, and reduce greenhouse gas emissions…"

"…additional research is needed to evaluate Tier 2 and Tier 3 measurements and interpret their contributions to soil health in different climates, soils, and production systems."

Soil Health Institute (USA)
"Tier 2 Indicators"

TABLE 2. Tier 2 Soil Health Indicators and Methods to be Assessed (updated 10/23/2018)

Indicator	Method	Reference
Sodium Adsorption Ratio (SAR)	Saturated paste extract followed by atomic absorption or inductively coupled plasma spectroscopy	Miller, et al., 2013
Aggregate Stability	Image Recognition	Farjardo,et al., 2016
Soil Stability Index	Combination of wet and dry sieving at multiple sieve sizes	Franzluebbers, et al., 2000
Active Carbon	Permanganate oxidizable carbon (POXC). Digestion followed by colorimetric measurement	Weil, et al., 2003
Soil Protein Index	Autoclaved Citrate Extractable	Schindelbeck, 2016
B-Glucosidase	Assay incubation followed by colorimetric measurement	Tabatabai, et al., 1994
N-Acetyl-B-D Glucosaminidase	Assay incubation followed by colorimetric measurement	Deng and Popova, 2011
Phosphomonoesterase	Assay incubation followed by colorimetric measurement	Acosta-Martinez and Tabatabai, 2011
Arylsulfatase	Assay incubation followed by colorimetric measurement	Klose, et al., 2011
Phospholipid Fatty Acid (PLFA)	Bligh-Dyer extractant, solid phase extraction, transesterification; gas chromatography	Buyer and Sasser, 2012
Genomics	16S rRNA, ITS, and shotgun metagenomics	Thompson, et al., 2017; Quice, et al., 2017
Reflectance	Diffuse reflectance spectroscopy	Veum, et al., 2015

Soil Quality Website (Australia)

soilquality.org.au

Type of soil property	Soil quality indicator
Biological	Total organic carbon
	Microbial biomass
	Diseases & nematodes
	Molecular fingerprinting
	Potential soil nitrogen supply
Chemical	pH
	Cation exchange capacity
	Nutrients
Physical	Bulk density

Australian Government

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Soil Biology Initiative II Supported by the GRDC

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wheatbelt natural resource management

Department of Agriculture and Food

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Data matched for 'good' and 'poor' based on locations across Australia

this addresses ***climate & soils for crop production***

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wheatbelt natural resource management

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Examples of soil biology tests
[tests related to occurrence]

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Microbial biomass (C, N, P)

Specific organisms (e.g. rhizobia, earthworms)

Groups of organisms (e.g. mites)

Plant pathogens (e.g. Predicta-B)

Arbuscular mycorrhizal fungi (hyphae in soil / in roots)

Soil biodiversity (e.g. DNA-based assessment)

Fungal / Bacterial Ratio

PFLA (Phospholipid Fatty Acid) signatures

Soil carbon fractions
(e.g. light fractions, soluble fractions, humic fractions etc)

Examples of soil biology tests
[tests related to activity]

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Soil Respiration (CO_2 evolved)

Substrate Induced Respiration (SIR)
Substrate Induced Nitrification (SIN)

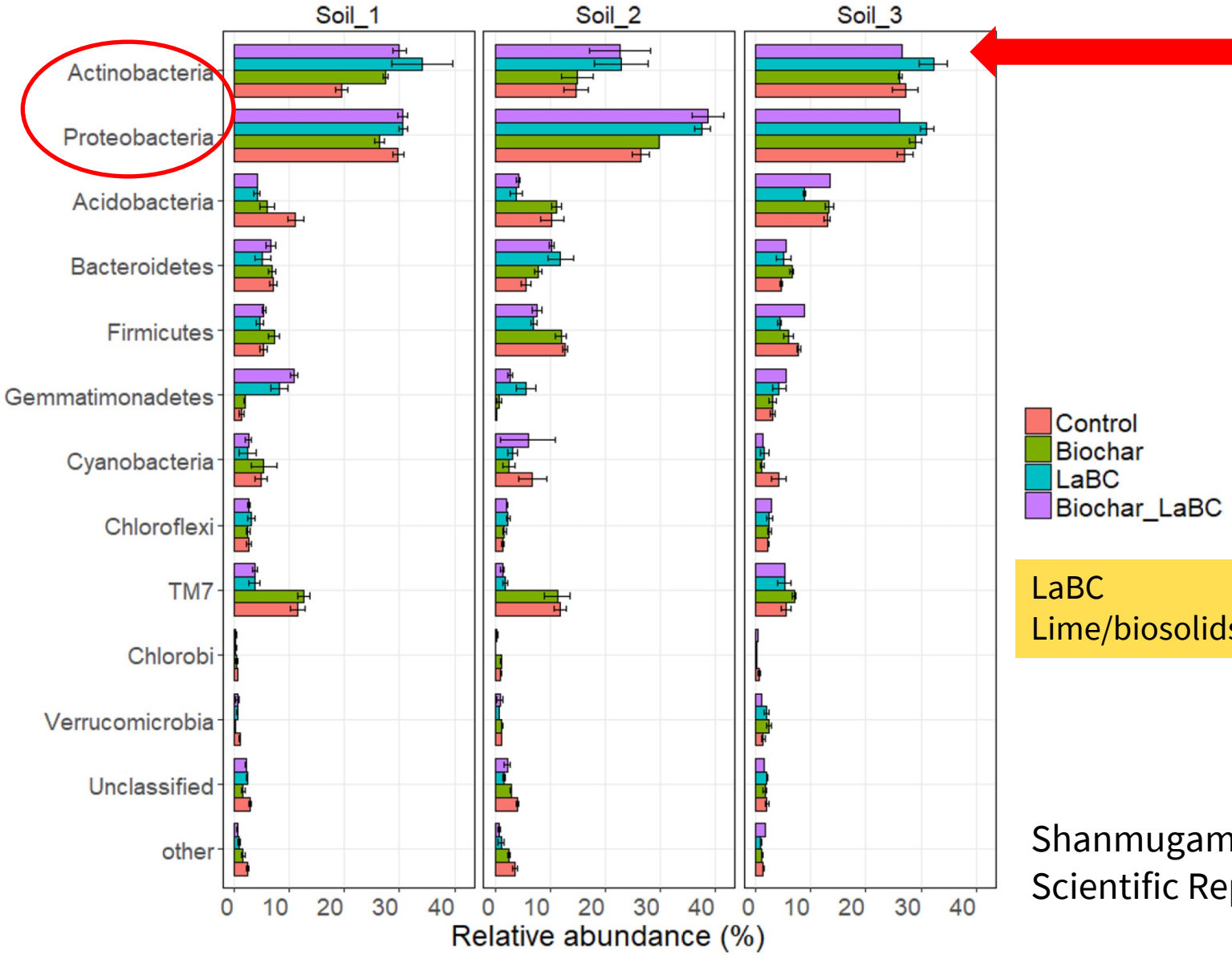
Enzyme activity (e.g. phosphatase)

BIOLOG
(response of soil to presence of a range of C substrates
= rates of degradation)

Functional gene potential (e.g. DNA-based assessment)

Arbuscular mycorrhizal fungi (hyphal activity in roots)

Example of DNA (molecular test): Relative abundance of bacterial phyla

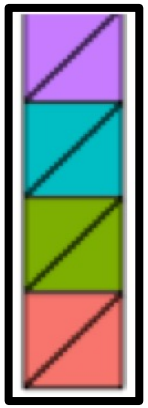


LaBC
Lime/biosolids/clay

Shanmugam et al. 2021
Scientific Reports 11:955

Dairy pasture management - field experiment - compost/manure

Large scale field experiment
(1 ha plots) on 3 dairy farms
Bunbury region



Manure 2t/ha + fertiliser

Compost 6t/ha + fertiliser

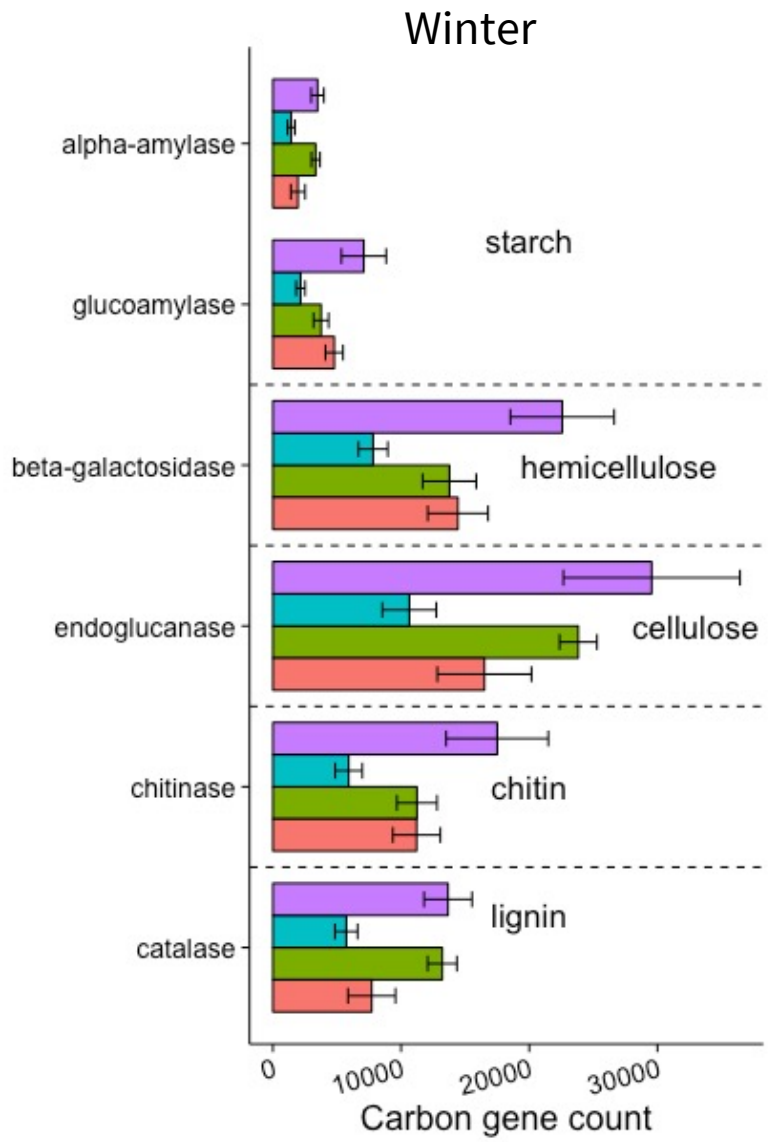
Compost 3t/ha + fertiliser

Fertiliser only

SWCC south west catchments council

ROYALTIES FOR REGIONS

Dairy pasture management - field experiment - Functional gene abundance (- “activity”)



Predicted functional gene counts – for carbon fractions

SWCC south west catchments council

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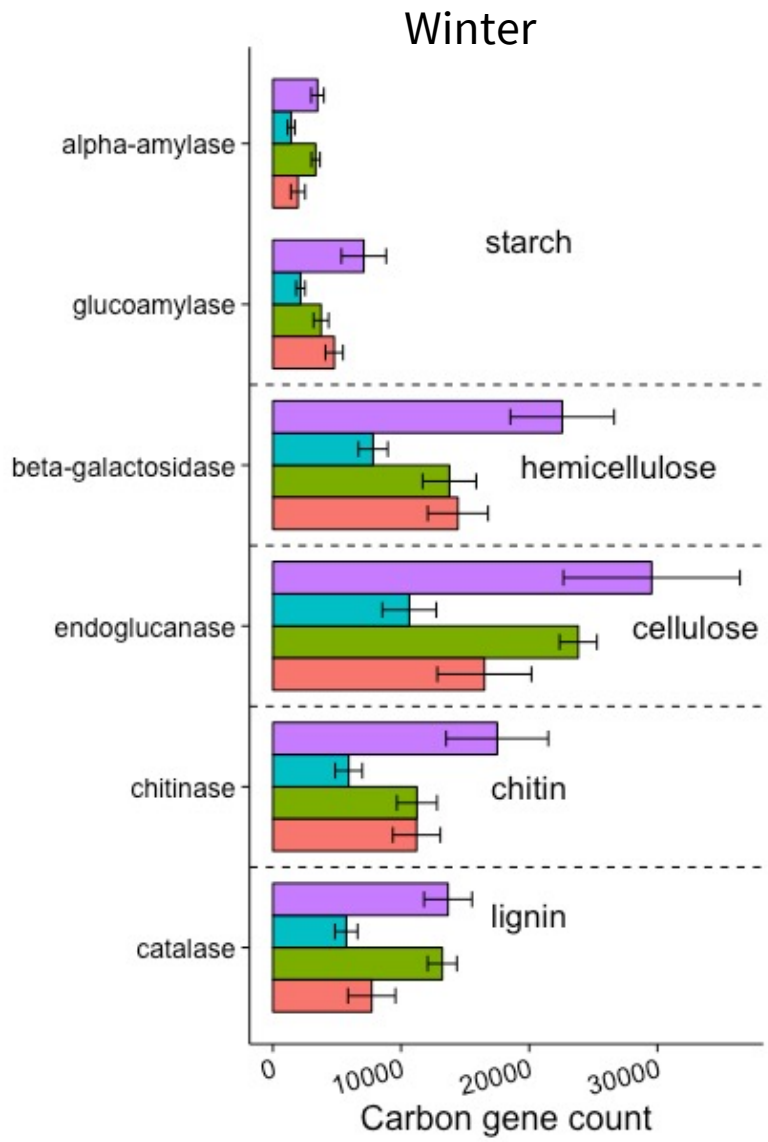
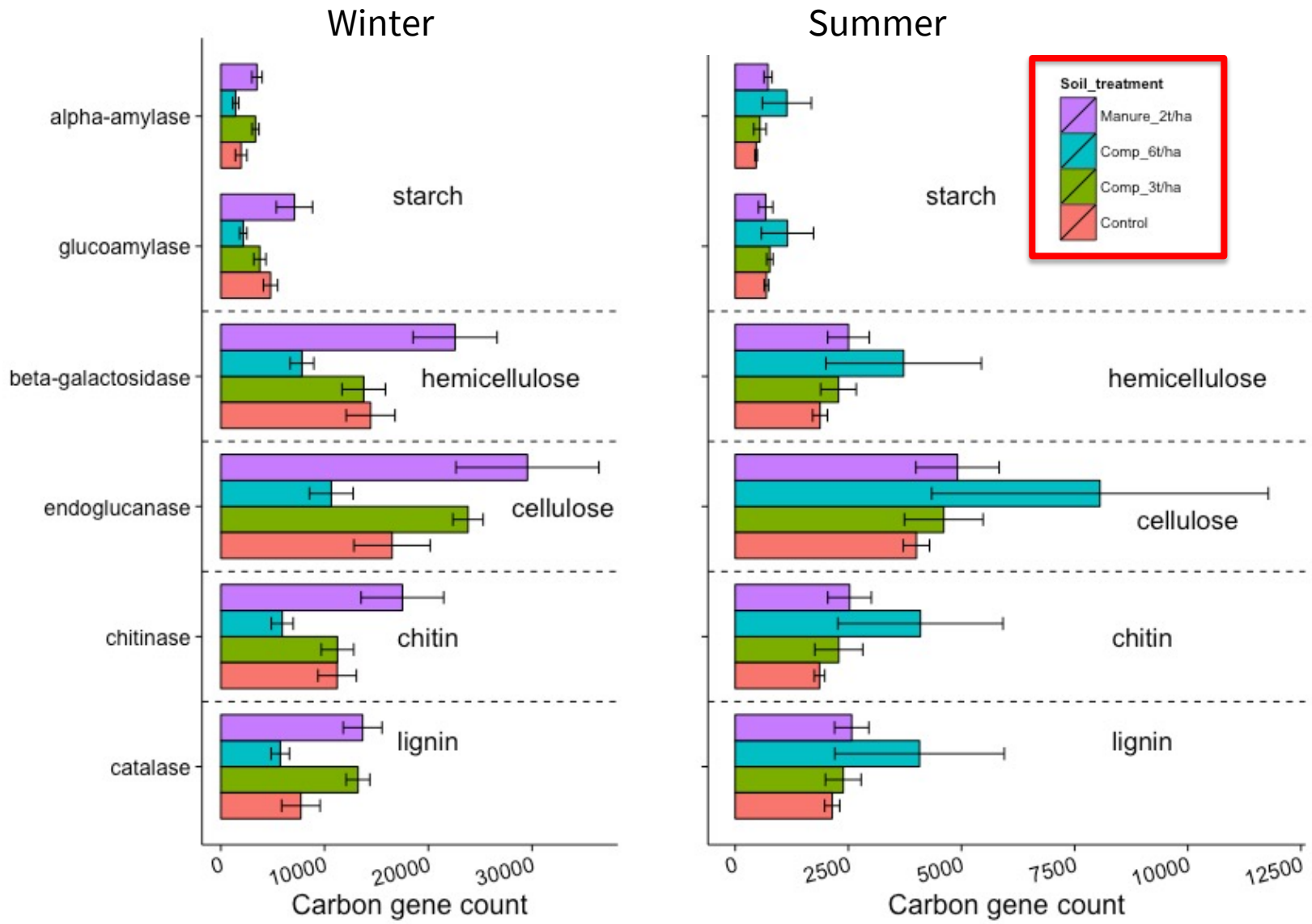


Soil amended with **6t/ha compost** had lower predicted functional gene counts (PICRUSt)
than soil amended with **3t/ha compost**
(at this time)

Changes in bacterial activity can occur without **measurable** changes in soil %C

IMPLICATION:
Soil biological processes that involve N and C cycling can occur without a change in soil chemical tests

Dairy pasture management - field experiment - Functional gene abundance (- “activity”)



Sampling for soil biology tests

WHAT to sample? – depends on the question

WHEN to sample? – depends on seasonal effects

WHERE to sample? – depends on site variability

HOW MANY samples? – depends on soil test

HOW OFTEN to sample? – depends on the reason

SOIL ACTION PLAN

Soil Action Plan - measuring and monitoring soil health	
Description of Site	
Objective of management	
Predicted effects of management	
Timeline of effects of management	

SOIL ACTION PLAN

Soil Test	Expected value, sampling details (e.g. time(s), depth)
Soil Test 1	
Soil Test 2	
Soil Test 3	

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