Soil Carbon and Productivity

Carbon on your Farm
Soil Health and Salinity Update
Coomandook
6 April 2022

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Government of South Australia
Department of Primary Industries and Regions

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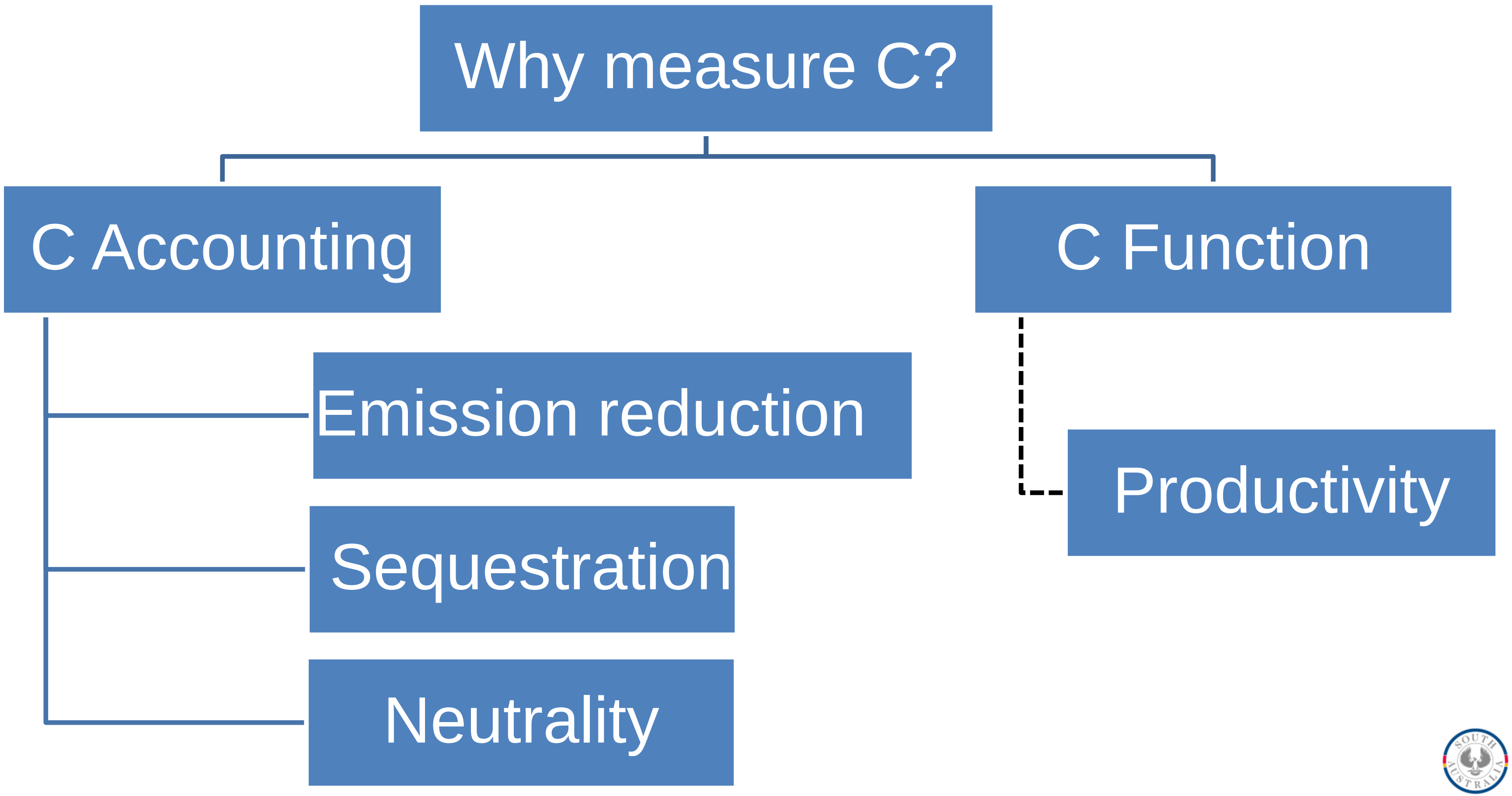
Department for Environment and Water

SOIL CRC
Performance through collaboration



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Carbon Neutral

- businesses and organisations are choosing to reduce their climate impact to zero by becoming carbon neutral
- gain certification (e.g. Climate Active, Industry targets)

To do this:

1. **calculate** the greenhouse gas emissions – C Footprint
2. **reduce emissions** as much as possible by investing in new technology or changing the way you operate
3. **offset** any remaining emissions by sequestration or purchasing carbon offset units

Carbon Projects – Emission Reduction Fund

- Earn Australian Carbon Credit Units (ACCUs) by participating in specific activities under emission reduction or sequestration projects
- ACCUs can be sold to generate income either to the government or in a secondary market
- Contracts with Clean Energy Regulator (CER)

You can not sell ACCUs and use to become C Neutral

http://www.cleanenergyregulator.gov.au/ERF/Forms-and-resources/auctions-and-contracts/contracts-frequently-asked-questions#5

ERF – Soil C Projects

45 soil C projects

Grazing – stocking rate, duration or intensity	**7**
Grazing - nutrients, pasture rejuvenation	2
Nutrients, pasture where was none, stocking rate	**17**
Nutrients	**8**
Nutrients, stubble retention, tillage, stocking rate	**6**
Nutrients, stubble retention, pasture where was none, stocking rate	3
Nutrients, pasture by seeding/pasture cropping	1
Nutrients, stubble retention, tillage, stocking, pasture was none, rejuvenation, **redistribute soil in soil profile**	1

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Soil Carbon Projects - ERF

How much is change worth?

If soil OC ↑ over 5 years by **0.5%** = **7.70 tCO_2e/ha**

Discounts (minus from original value)	tCO_2e/ha
5% for uncertainty	7.32
25% for 25 year contract	5.49
GHG emissions for 5 year sampling period not calculated	?
20% C broker fee	4.39

$/tCO2e/ha	Before discounts	After discounts
$16.94	$130	$74
$50.00	$385	$220

Assumptions
OC = 0.5 %
Bulk density = 1.4g/cm^3
Soil depth = 30 cm
= 2.1 tC/ha
= 7.7 tCO_2e/ha

Bulk density and gravel remains the same 5 yrs

C broker fee between 15-25%

Still need to pay for soil sampling and independent land management report

What is soil C?

TC = OC + IC

OC is a part of organic matter

Inorganic (IC) and organic (OC) forms

- IC (carbonate) is mineral based and not influenced by land management practices (except liming)
- OC is living or decomposing organic compounds of plants, animal and microbial origin
  - influenced by land management practices
  - makes up ~ 58% of the mass of soil OM
  - SOM = Total SOC x 1.72

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Soil C tests

OC (Walkley Black method) most often used for general monitoring

- Good for soils containing carbonate but does not measure the total OC in the soil
- OC_{wb} represents 75-90% of the Total OC result

If C accounting - Total OC needs to be measured

- Total C – measures all carbon in soil and good test for soils without carbonate
- Total OC – use for soils containing carbonate. Acid pre-treatment removes the carbonate prior to testing.
  - where soil **has** high to very high fizz: carbonate needs to be fully removed by acid pre-treatment. OC_{wb} test can provide a guide.

Need to select the correct test depending on why you are sampling

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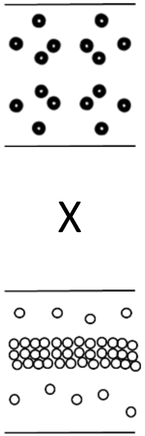
Carbon Stock



Stock is the unit used in soil carbon accounting

Soil OC stock is reported as
- t C / ha (same as Mg C / ha)
- or CO_2 equivalents 1 t C / ha = 3.67 t CO_2e
- generally in the top 30 cm of soil

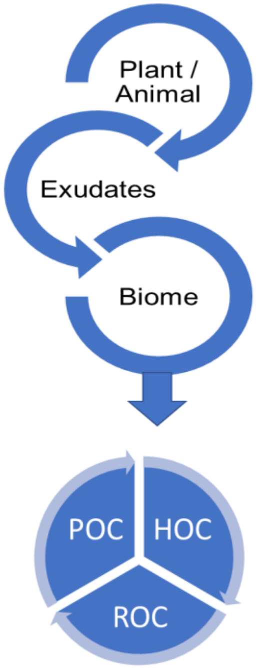
To calculate stock need the soil bulk density (mass of soil / volume of soil) and the gravel content of the soil

OC stock (tC/ha) =

OC (%) x bulk density (g/cm^3) x depth (cm) x (100 - gravel %)

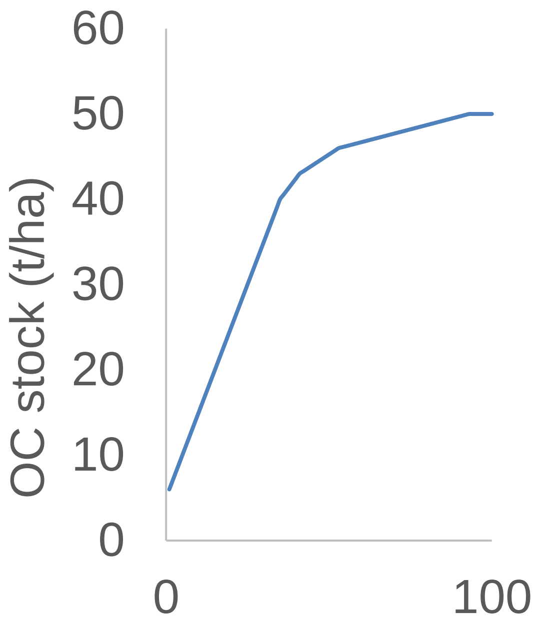
Why are we interested in carbon?

Increasing soil function



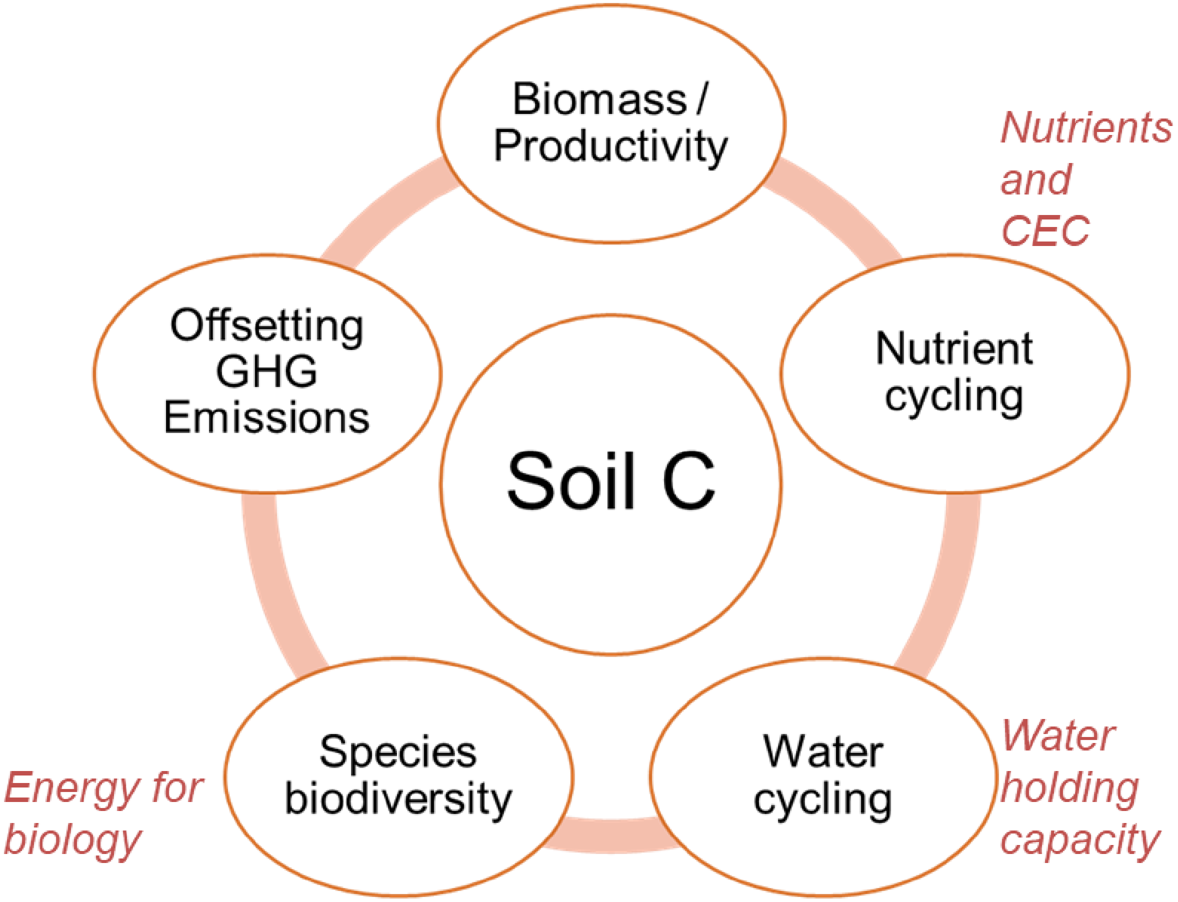
Will this increase OC?

Increasing OC over time



Will this increase function?

Functions underpinned by organic matter



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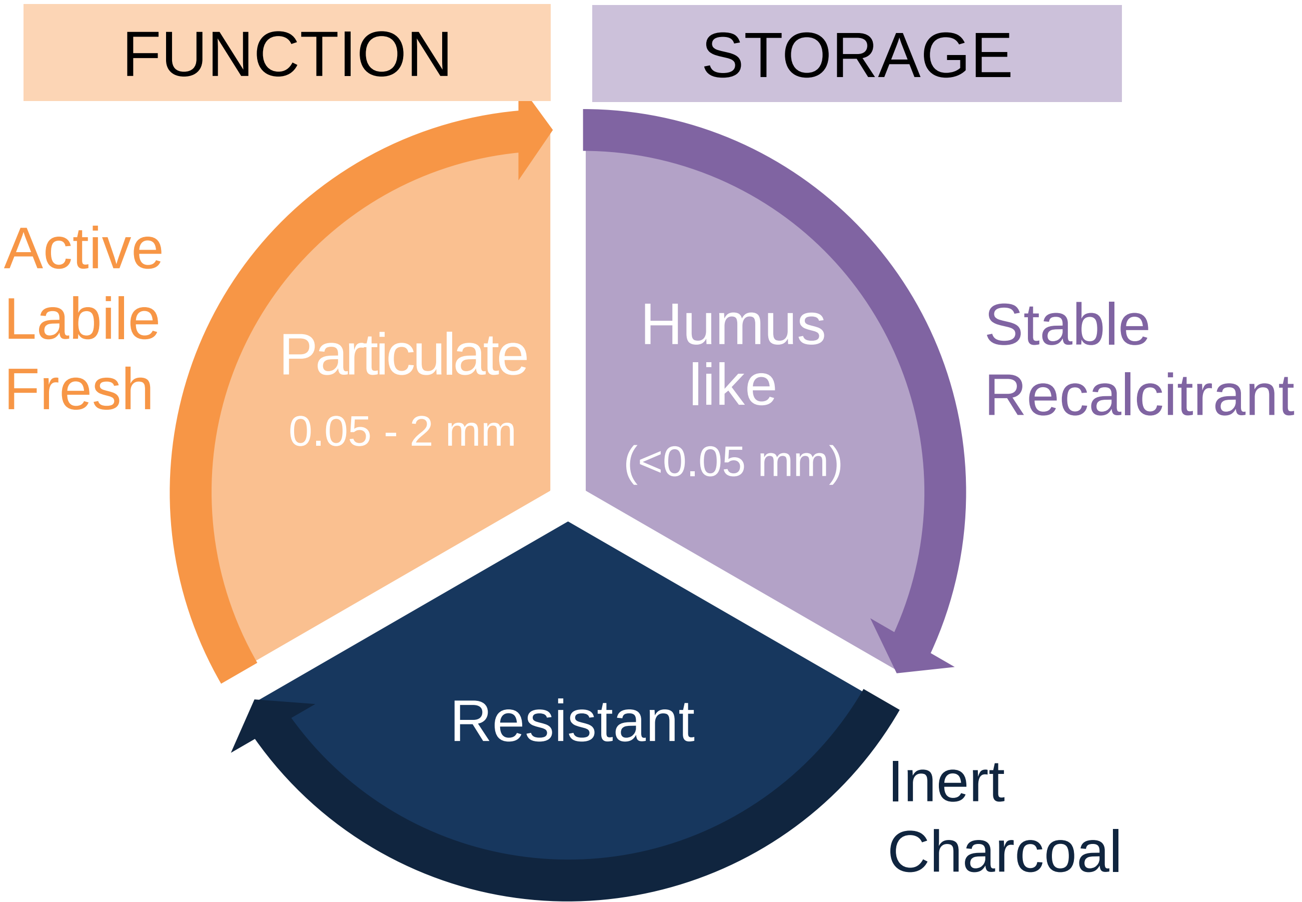
OC is made up of 3 fractions / pools



Soil biology is critical for OC turnover and nutrient release

<u>OC turnover</u>

POC = years

HOC = decades

ROC = centuries

After J. Baldock CSIRO

What factors influence soil OC?

OC input + OC loss = OC in soil

Potential SOC

Defining factors

- Soil type **Texture,** mineralogy, density

Attainable SOC

Limiting factors

- Solar radiation
- Climate **Rainfall**, temperature

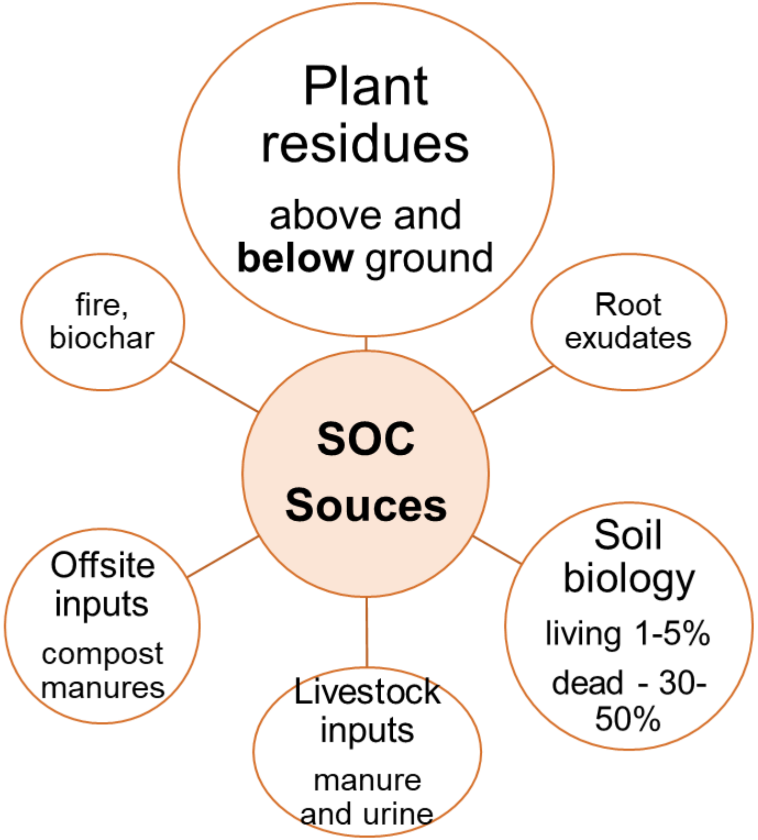
Actual SOC

Reducing factors

- Management practices

After Ingram and Fernandes 2001

How does OC get into the soil?



Decomposition losses are between 70-90% of C inputs

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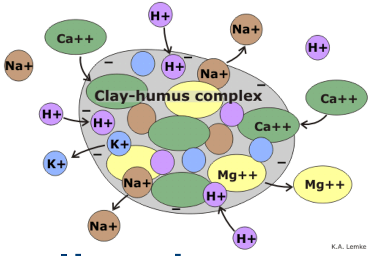
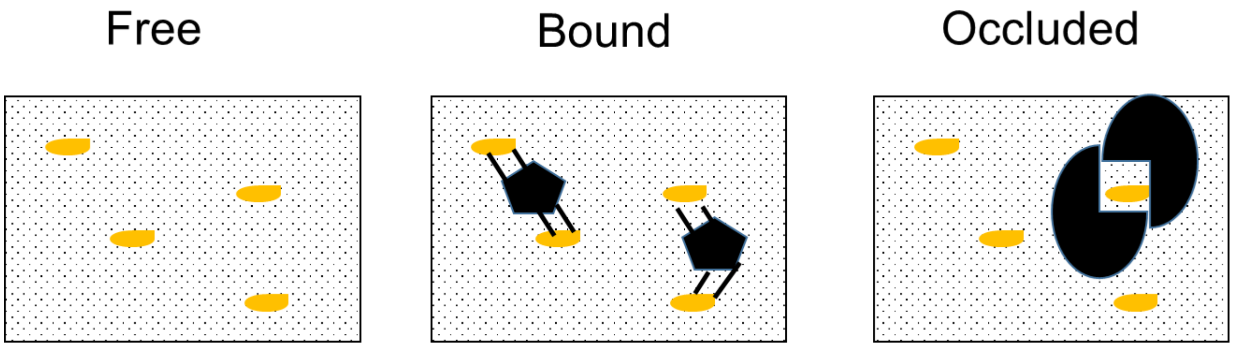
Soils capacity to stabilise OC



Soil has a finite capacity to protect OC from mineralisation

= capacity to bond OC



Decomposition risk = high

Decomposition risk = low

Decomposition risk = low

STABILISED with clay minerals, Fe, Al, Ca and aggregates (MOAM)

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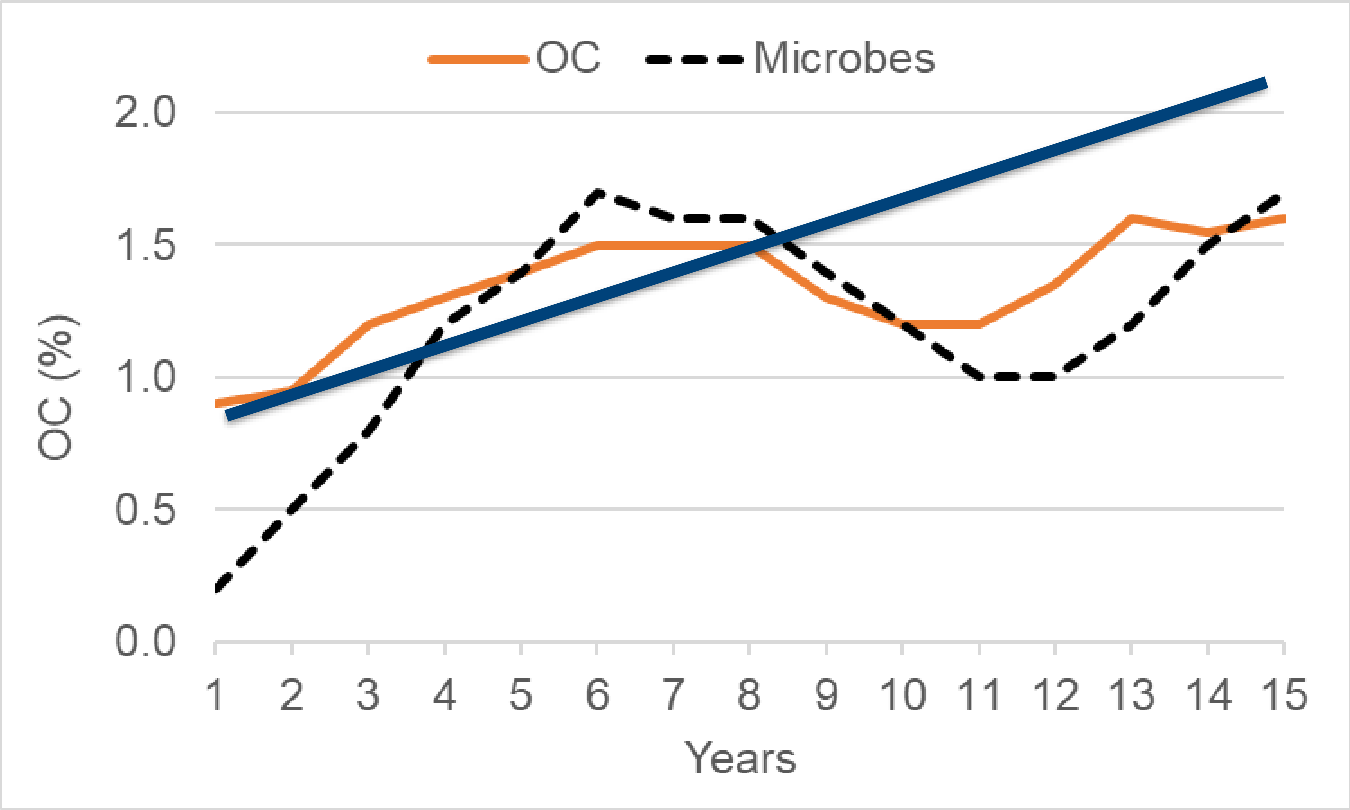
Soils capacity to stabilise OC



OC can be decomposed if not stabilised in soil

OC change is not linear

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Determining the OC opportunity

South Australian agricultural soils

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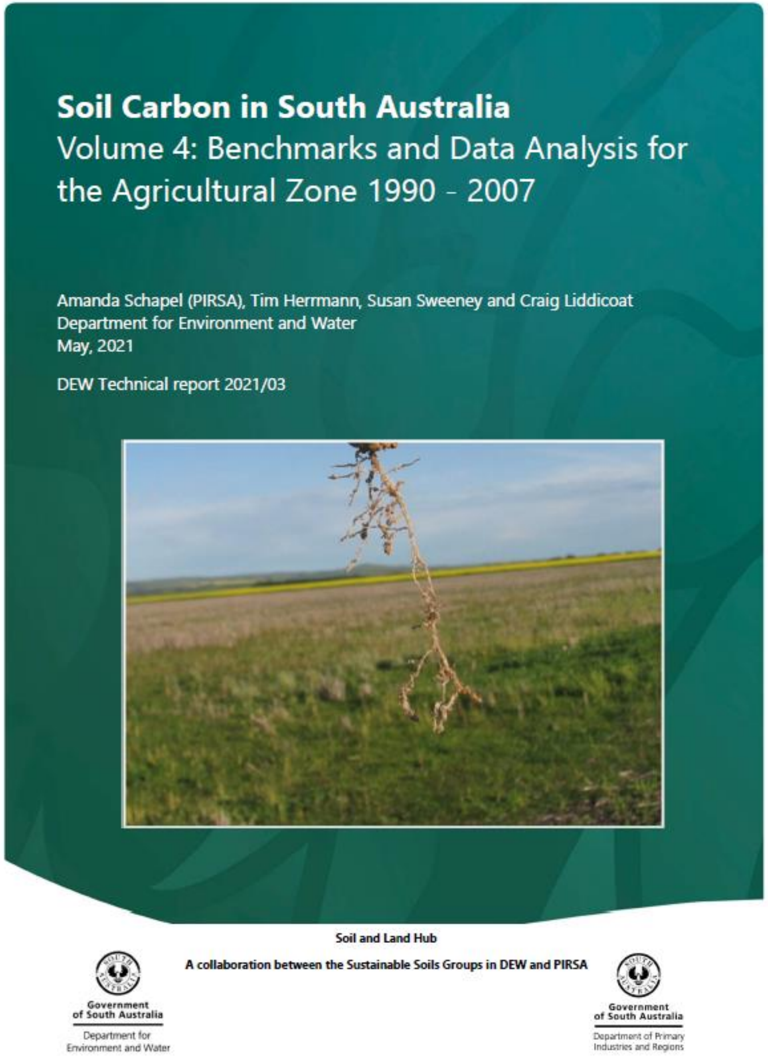
Soil Carbon Benchmarks for the agricultural zone 1990-2007

Soil and Land Hub – Collaboration between Sustainable Soils groups in DEW and PIRSA

May 2021

Land Resources Home (environment.sa.gov.au)
under All Reports for Soil C in SA Volume 4


Soil Carbon in South Australia
Volume 4: Benchmarks and Data Analysis for the Agricultural Zone 1990 - 2007

Amanda Schapel (PIRSA), Tim Herrmann, Susan Sweeney and Craig Liddicoat
Department for Environment and Water
May, 2021

DEW Technical report 2021/03

Soil and Land Hub
A collaboration between the Sustainable Soils Groups in DEW and PIRSA

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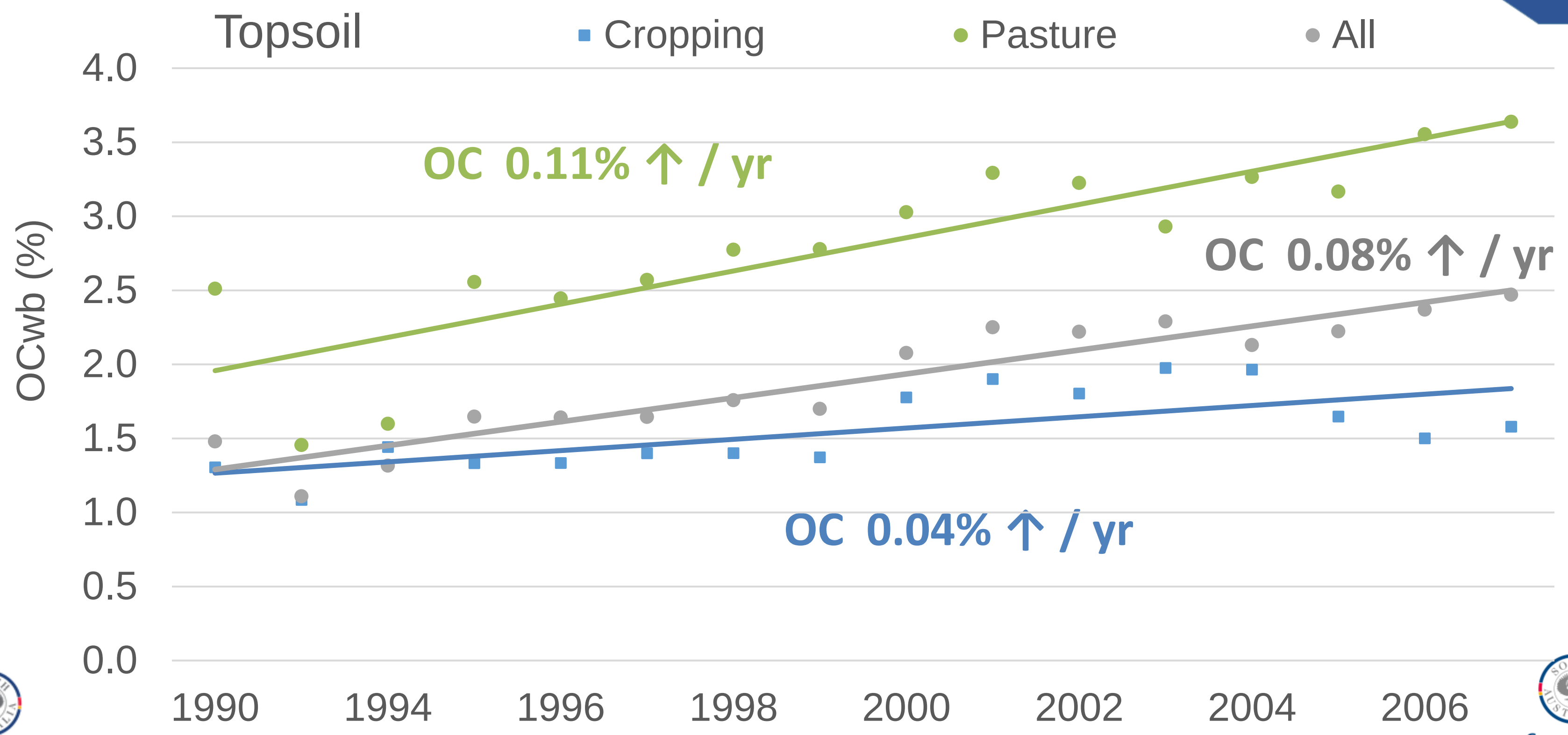
Soil Carbon 1990-2007

36,000 soil tests

0-10 cm



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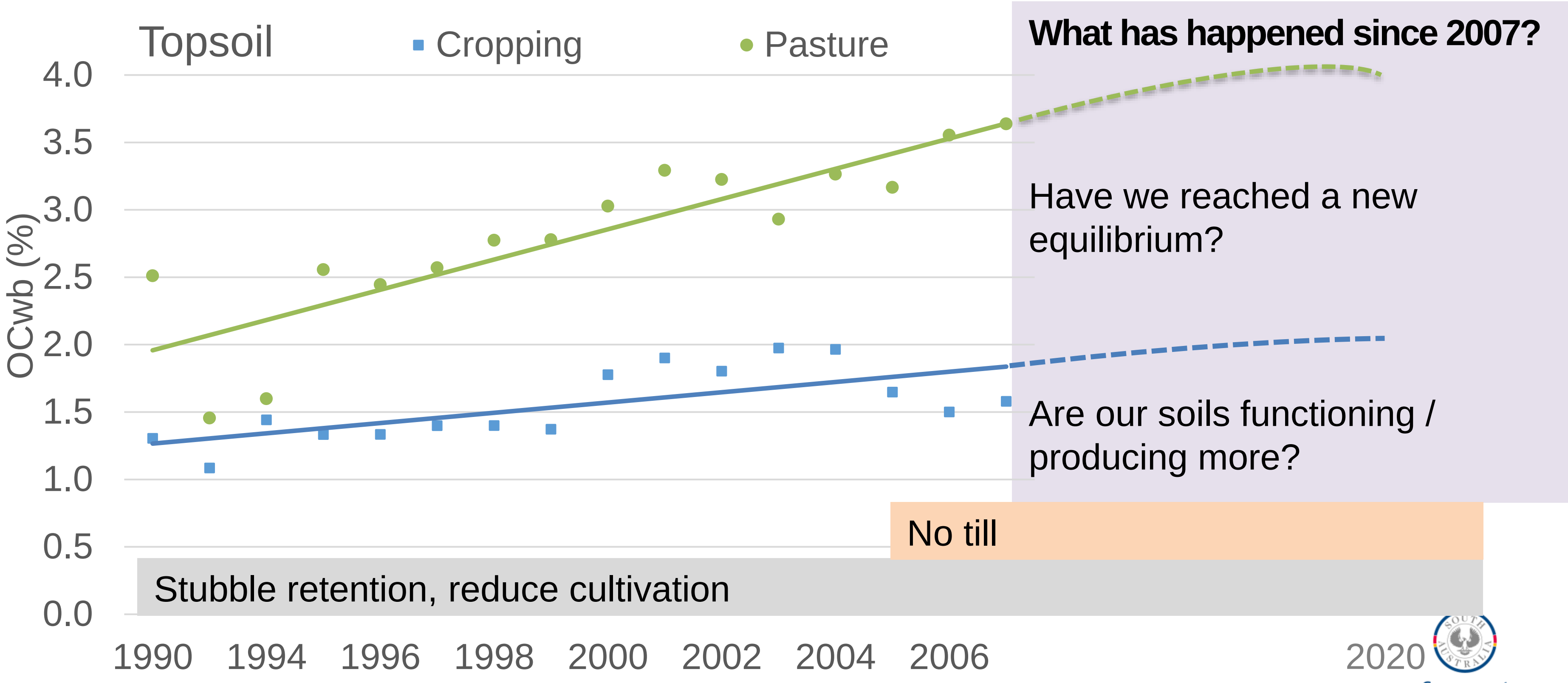
Soil Carbon 1990-2007



Soil and Land Hub – Collaboration between Sustainable Soils groups in DEW and PIRSA

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Upper SE OCwb 0-10cm 1990-2007

	Ag Zone	Ag District Benchmarks						
Texture	***Mean***	**Count**	**Mean**	**25%**	**40%**	**50%**	**60%**	**75%**
Sand	*1.12*	23	1.08	0.90	1.05	1.12	1.19	1.31
Loamy sand	*1.42*	933	1.21	0.85	1.01	1.10	1.24	1.51
Sandy loam	*1.79*	636	1.43	0.96	1.20	1.35	1.50	1.80
Loam	*1.96*	437	1.66	1.20	1.40	1.50	1.70	1.97
Clay loam	*1.93*	308	1.81	1.40	1.59	1.74	1.87	2.13
Clay	*1.66*	288	1.63	1.00	1.26	1.40	1.60	1.92
Weighted Mean (all texture)	*1.77*	2625	1.45	1.02	1.22	1.33	1.49	1.77

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Soil Carbon in SA Vol 4 - SA Ag Benchmark Analysis 1990-2007 June 2021 Final.pdf (environment.sa.gov.au)

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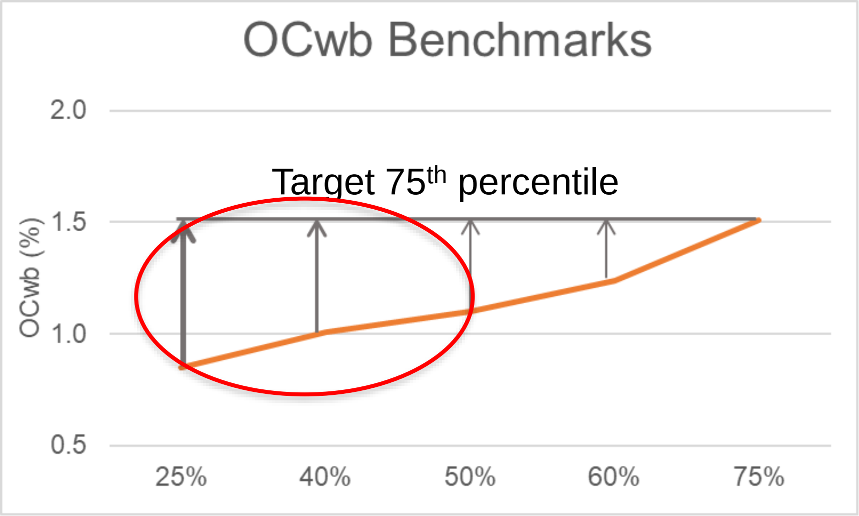
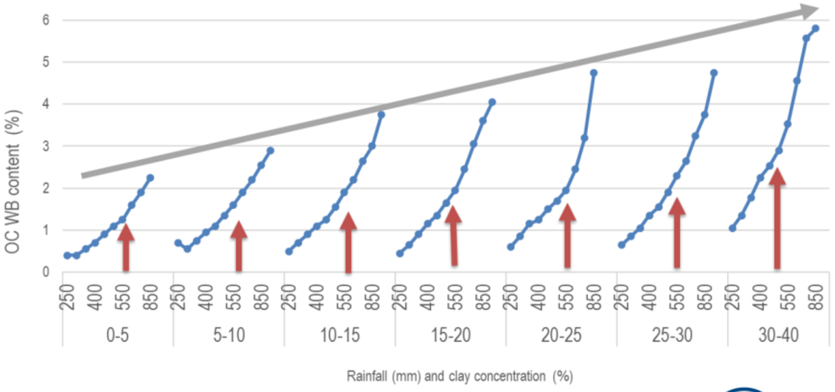
Opportunity to store soil OC

Higher potential for OC storage at lower OC concentration



Rainfall has a huge influence on C storage

sharp increase between 500-550 mm annual rainfall



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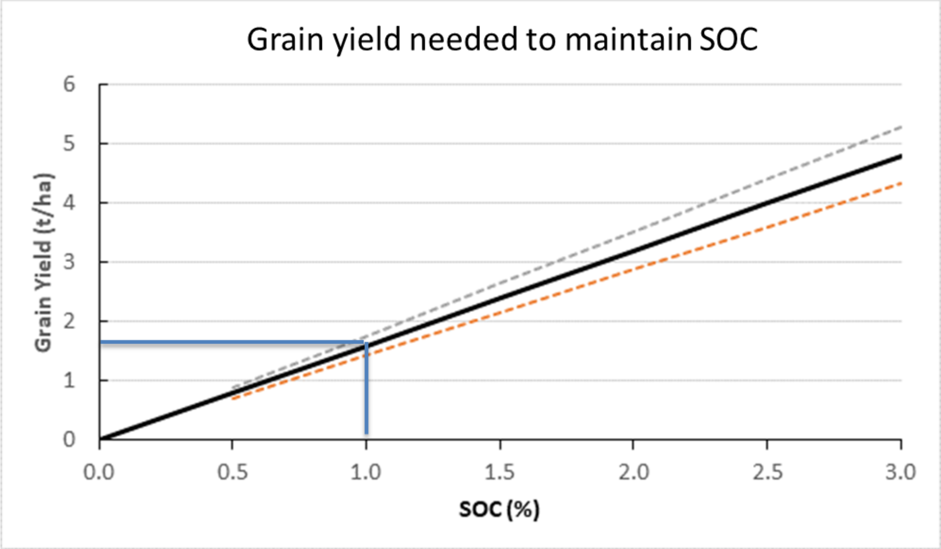
Opportunity to store soil OC

Ability to maintain OC inputs



Removal OC inputs with crops, hay, grazing burning etc

To maintain SOC at 1% need crop yield 1.7 t/ha

Source: Tim Herrmann from DEW Sustainable Soils

Sufficient nutrients

POC to HOC or Active to Stable

Nutrients required to create 1t humus

- 80 kg N
- 20 kg P
- 14 kg S

Clive Kirkby ratio

Estimated cost using synthetic nutrients $300

In NSW cereal-based systems extra nutrients

- with low (4t/ha) or normal stubble quantities
  X build stable soil C stocks
- where large amounts of stubble (12 t/ha)
  ✓ for enhancing soil carbon

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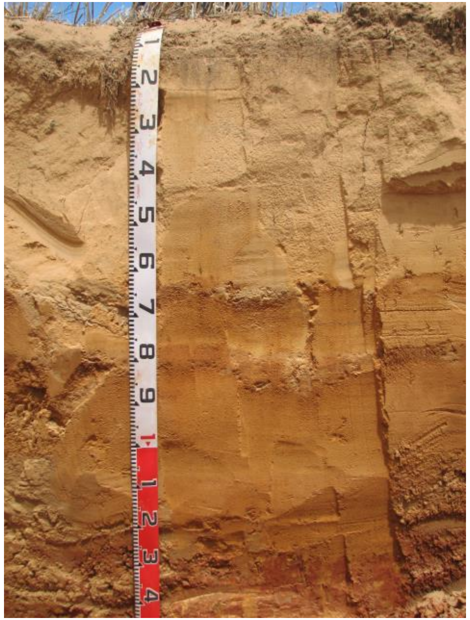
Opportunity to store soil OC

Soil limitations to OC inputs

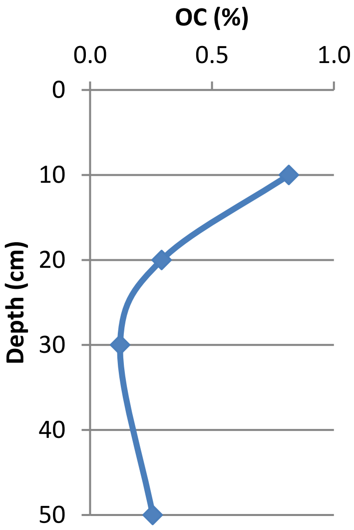


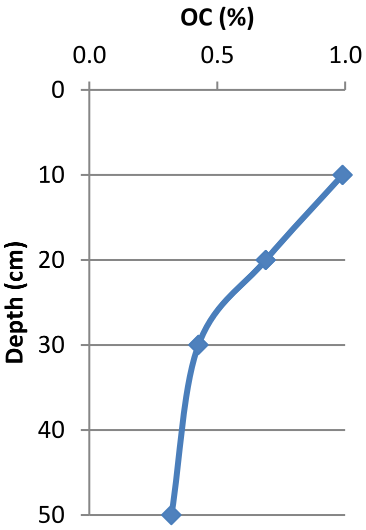
Chemical
pH, sodicity, nutrients

Biological
abundance, diversity,

Physical
compaction, density

Depth distribution of OC





Soil OC changes

South Australian examples

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Soil OC in Sandy Soils with Clay Addition

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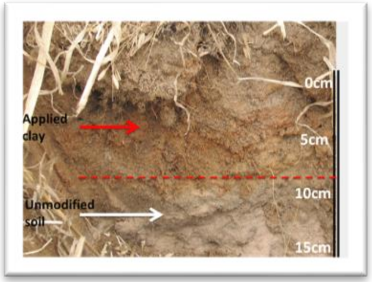
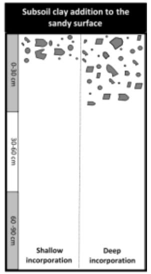
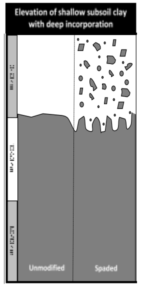
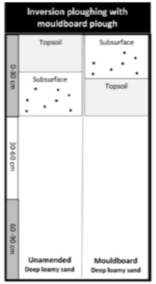
Sandy soil amelioration techniques

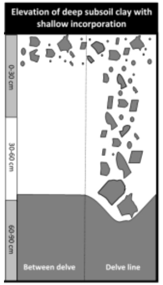
SANDY UNAMENDED SOIL





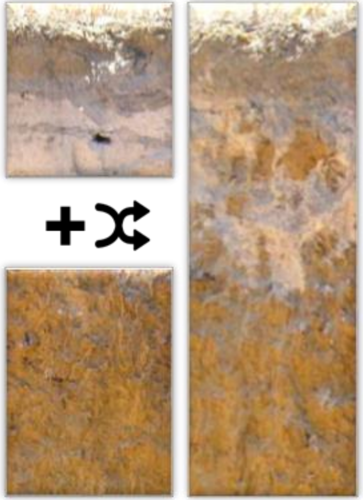






CLAY AMENDED SANDY SOIL

Key messages

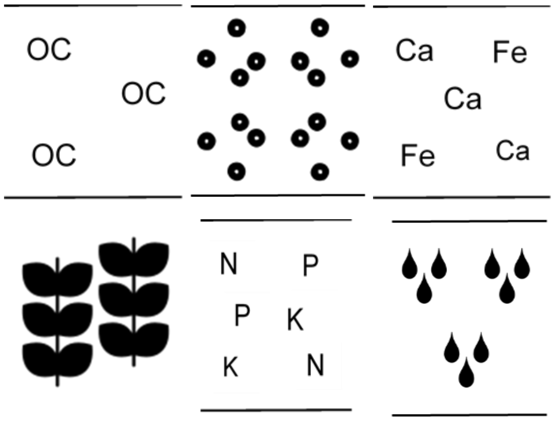


OC Stock$_{0-30}$

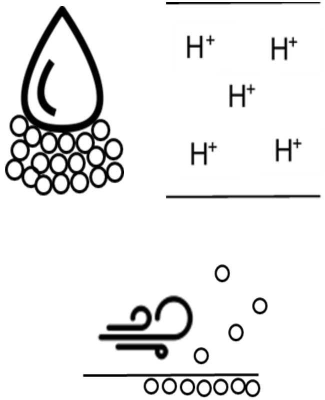
↑ **4.9** tC ha^{-1}

(-1.0 – 8.2 t ha^{-1})

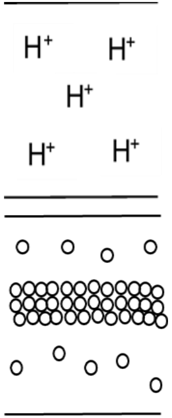
Increased

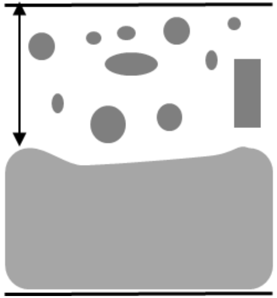


Decreased



Prone

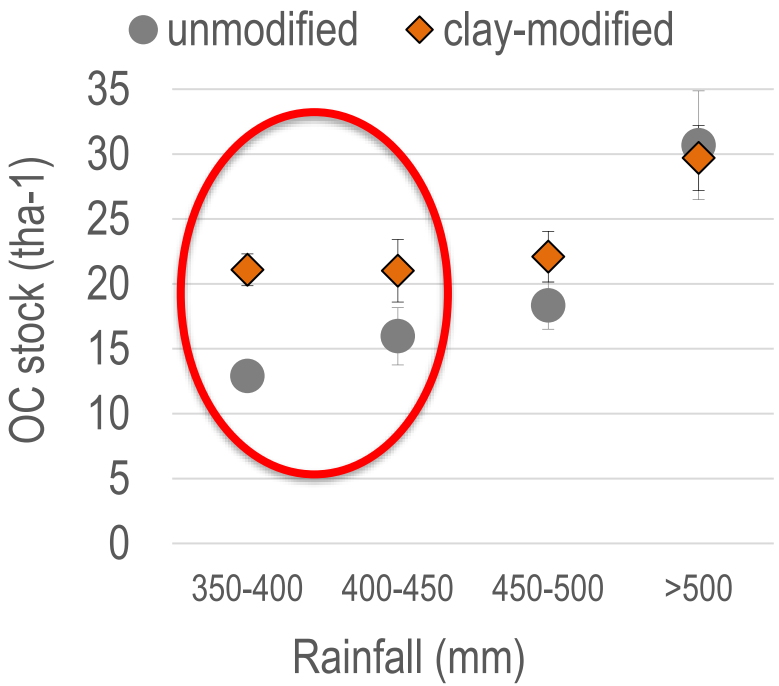


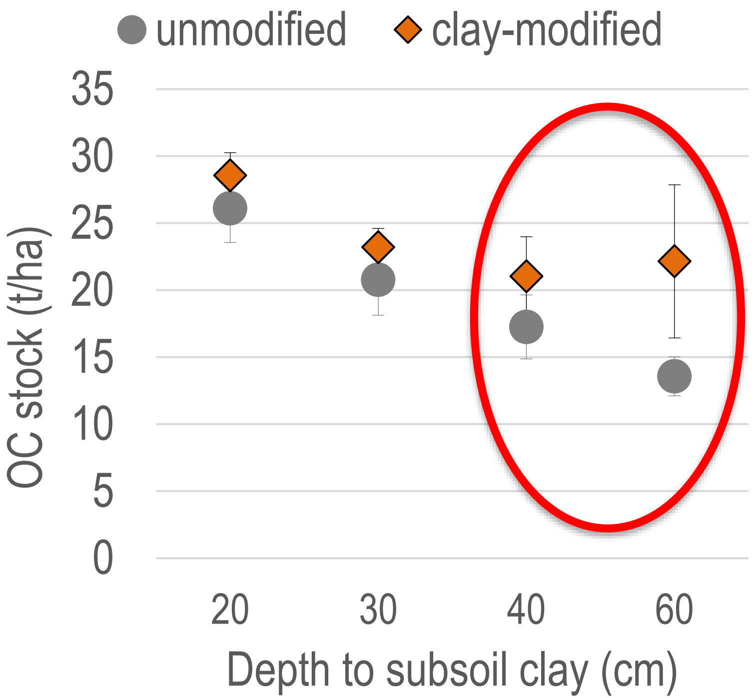


Clod size and number important for accumulation and protection of OC

For OC < 6mm size best in surface 20cm

Clay addition on OC stocks - Goyder/DEW





Highest OC stock at > 500 mm but unmodified also high

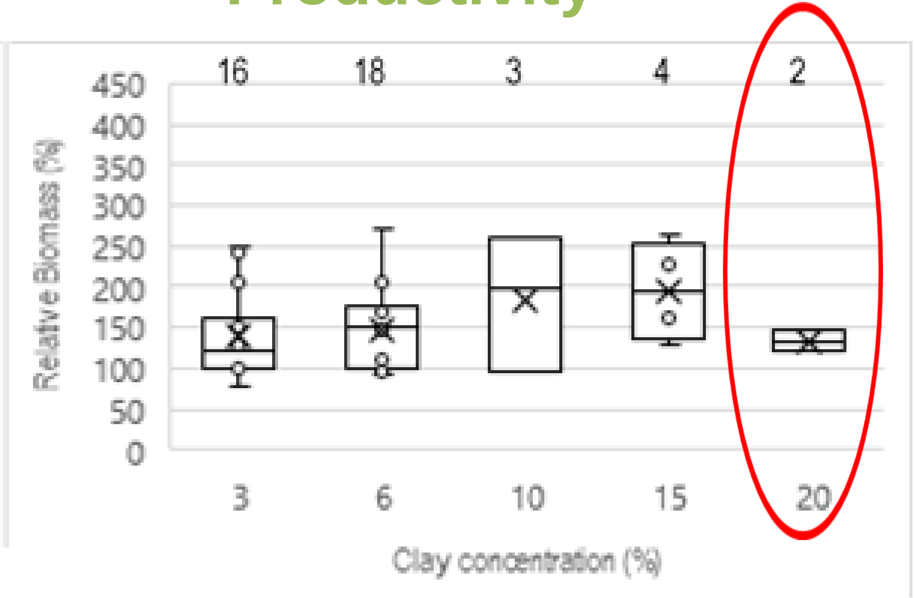
Greatest OC opportunity rainfall < 500 mm

Highest OC stock at where clay < 30 cm

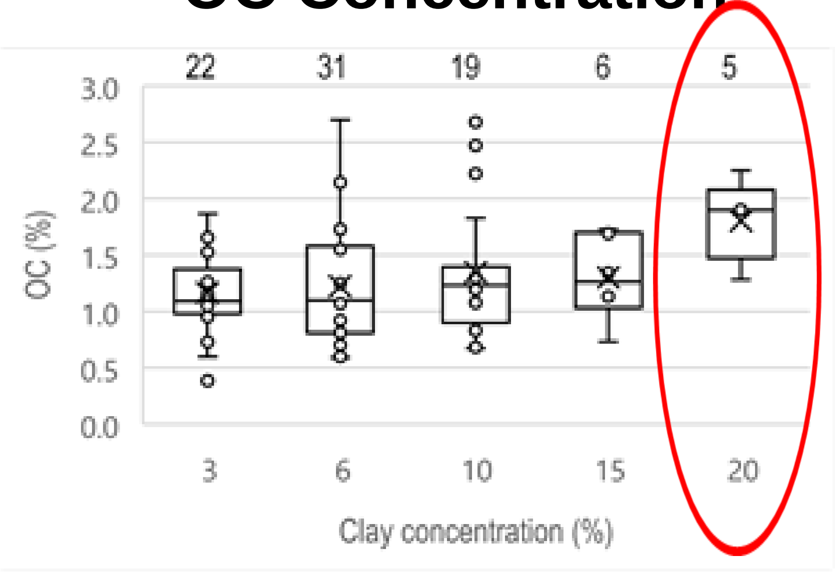
For greatest OC opportunity subsoil clay should be > 30 cm

Soil CRC Sandy Soil (2021) – Clay Concentration

Productivity



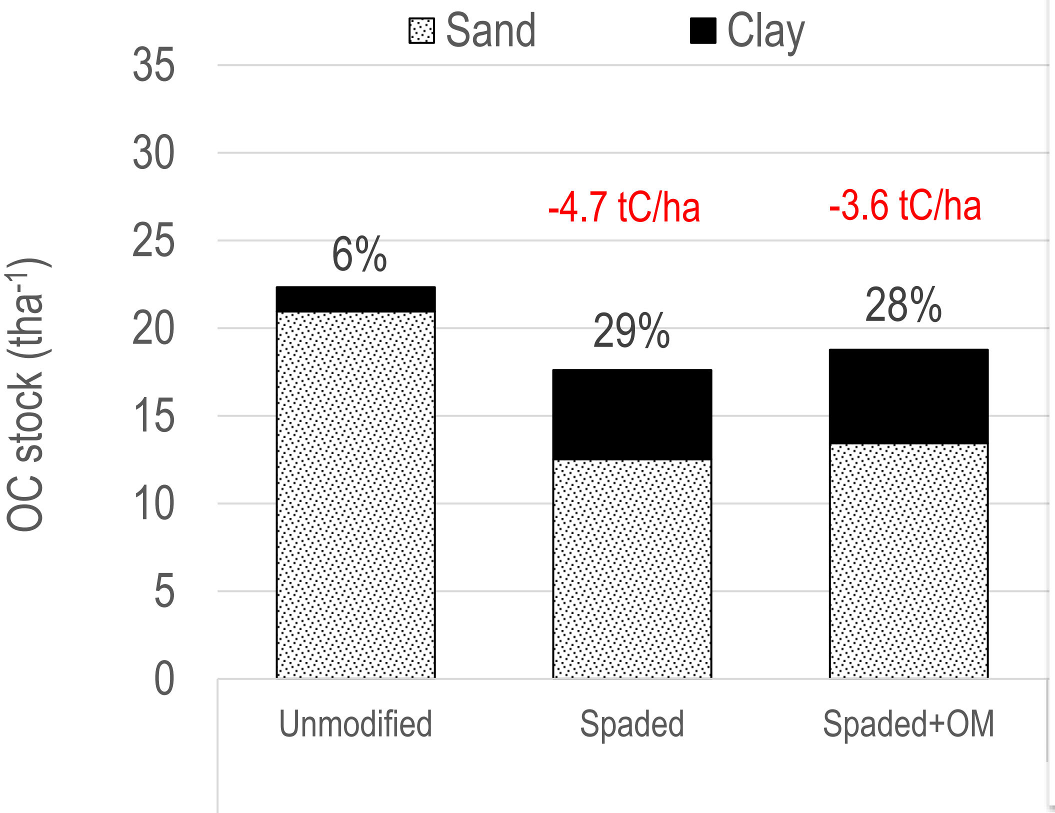
OC Concentration



270 records 0-10 cm

cumulative 0-30 cm

PhD (2018) - OC stock 0-30 cm clay and sand



*Schapel et al. 2019

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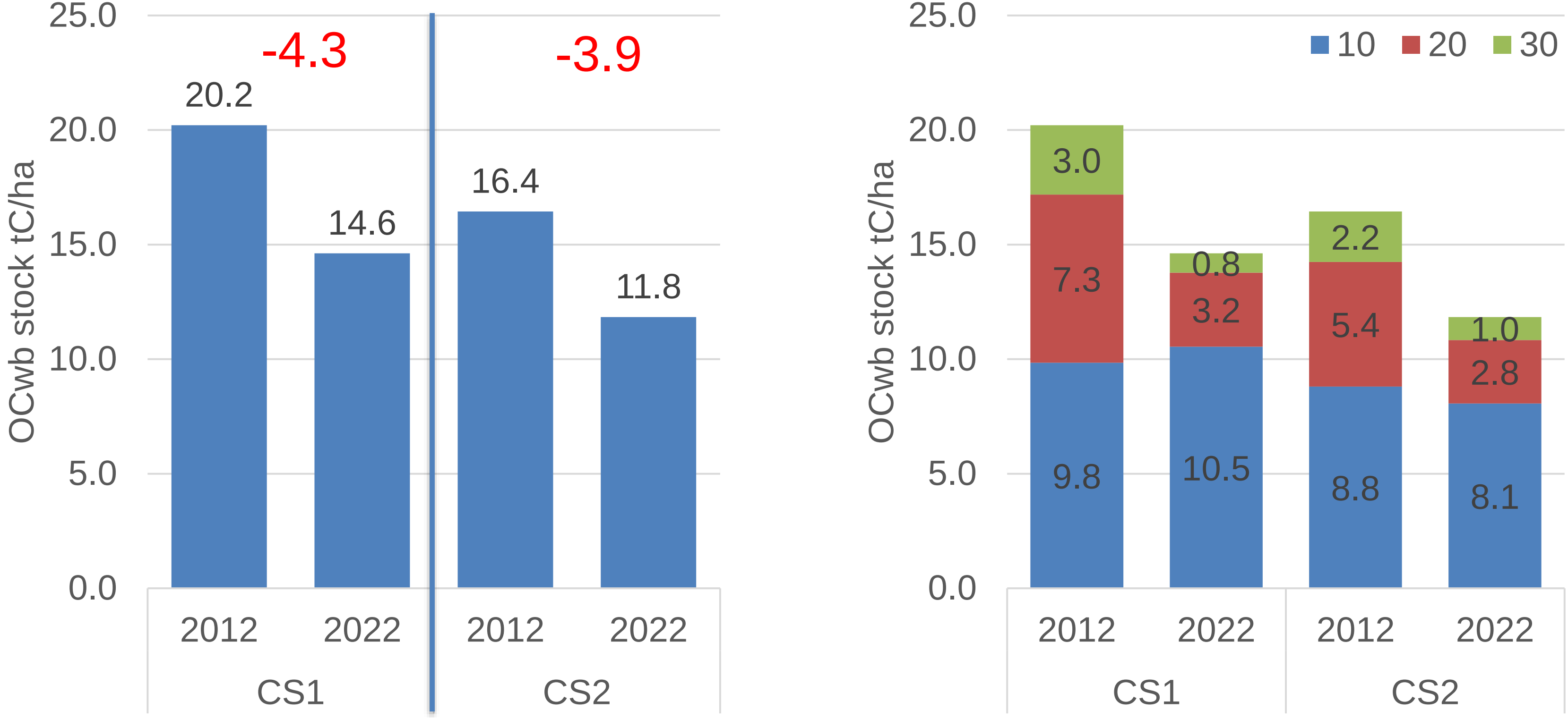
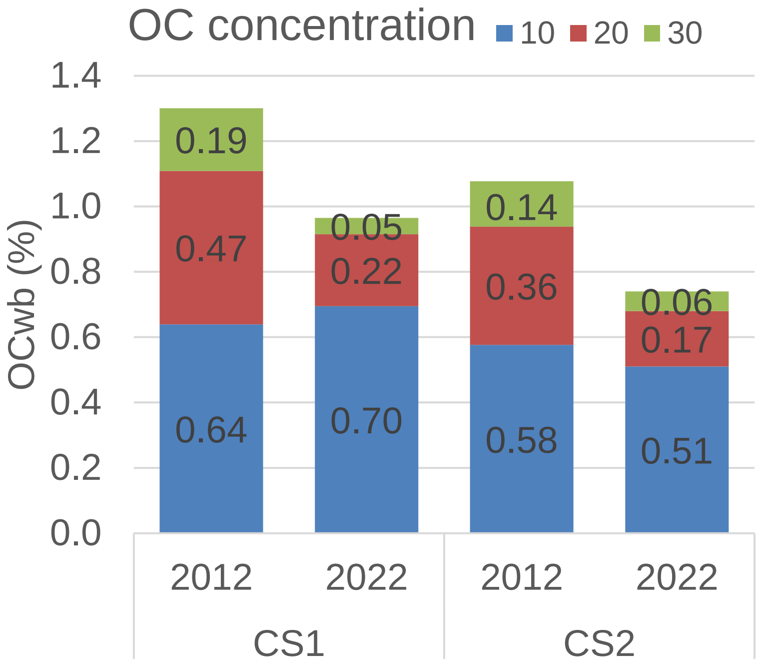
Sherwood Clay spread (2022) – CTLAP C Project

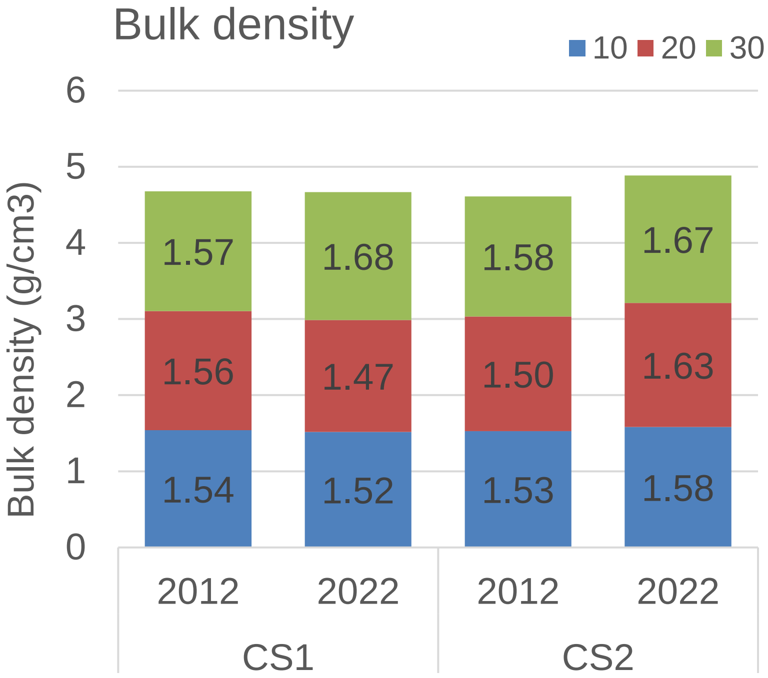
OC stock (tC/ha) 0-30 cm. Clay spread site resampled after 10 years



Sherwood Clay spread (2022) – CTLAP C Project

	Clay spread 250t/ha	Spaded	Sampled	Spaded	Delved	Offset disc x 2
CS1	1997	2010	2012	2012		
CS2	1998	2010	2012	2012	2020	2020





Lag time before changes measured?

<u>Productivity</u> changes are generally within 1-2 years

<u>OC</u> changes are often longer

After a change in practice

- 3-5 years up to 10 years in lower rainfall sandier soils

After fire event

- can be an immediate loss, highest seen is 30% in severe hot burn areas (under dense vegetation), minimal OC loss if soil still covered

After drought

- may not see an immediate decline unless soil is disturbed and uncovered
- OC may remain stable then a decline in 1-3 yrs that could take a few years to increase following return of production

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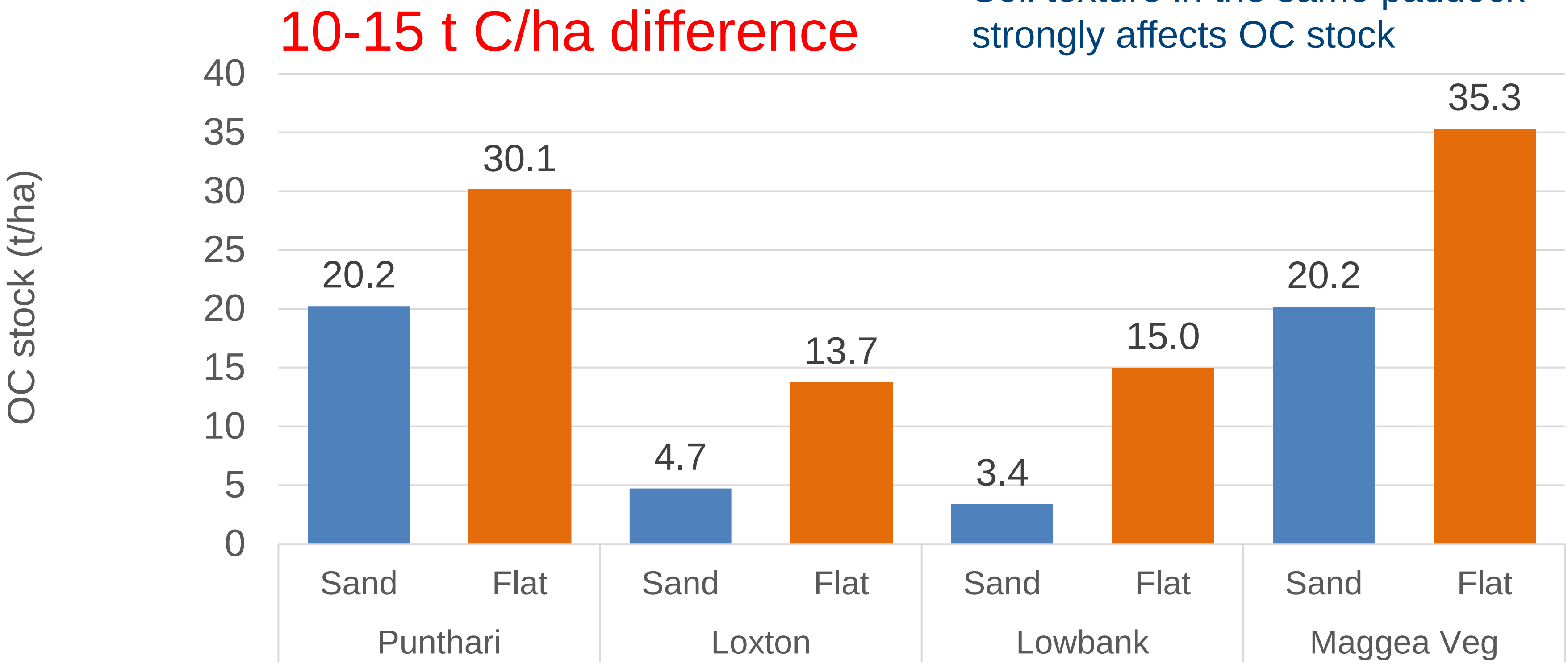
Soil texture

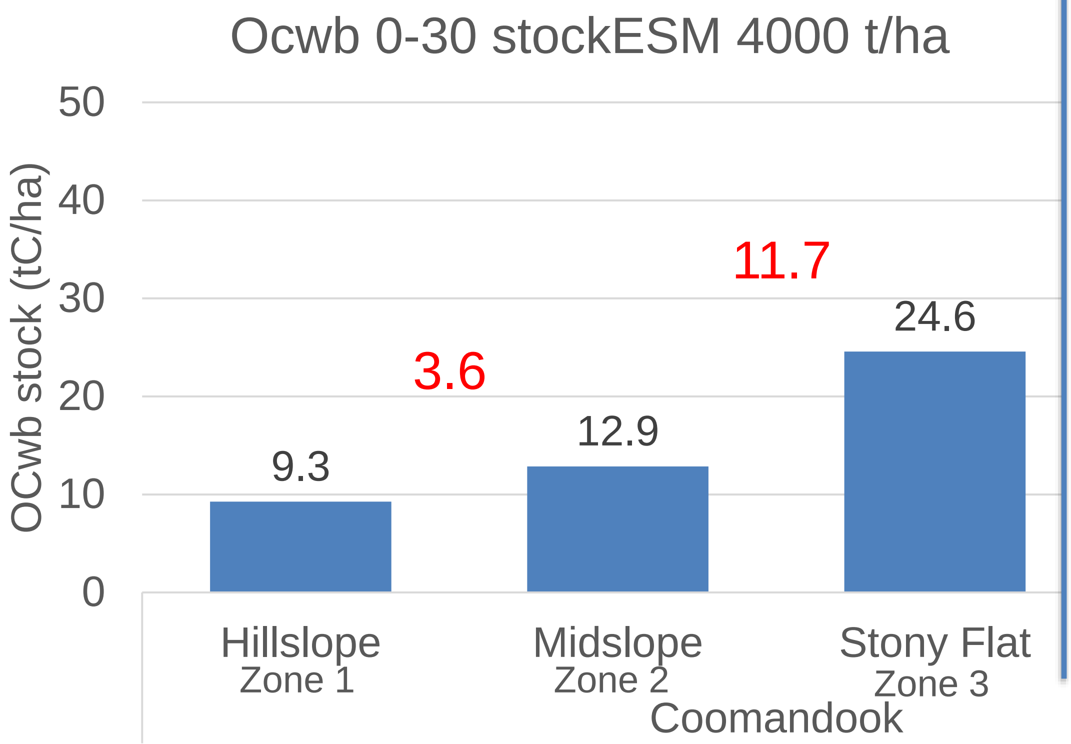
Soil texture in the same paddock strongly affects OC stock

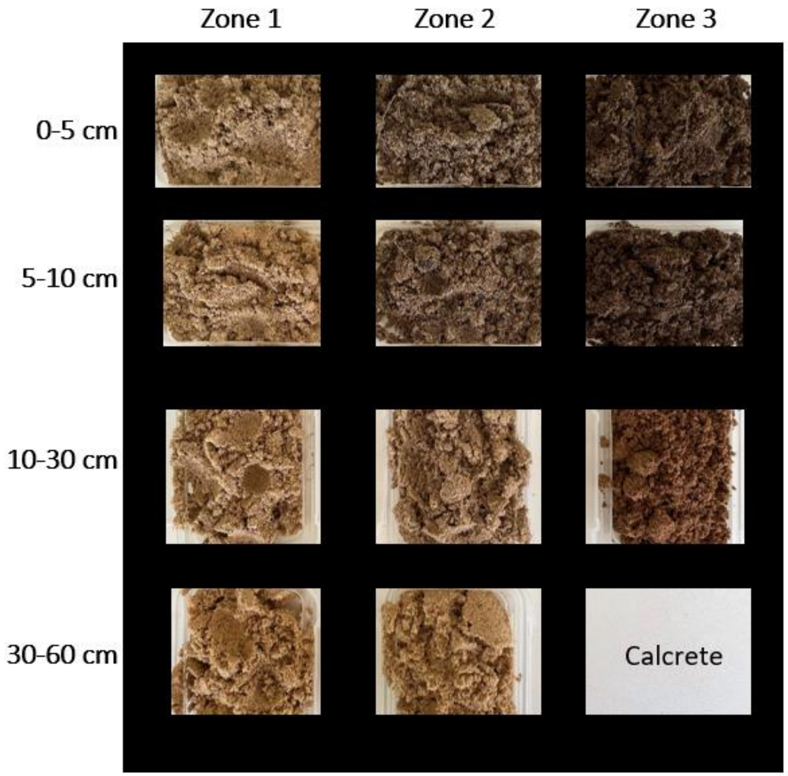


LANDSCAPE SOUTH AUSTRALIA
MURRAYLANDS AND RIVERLAND

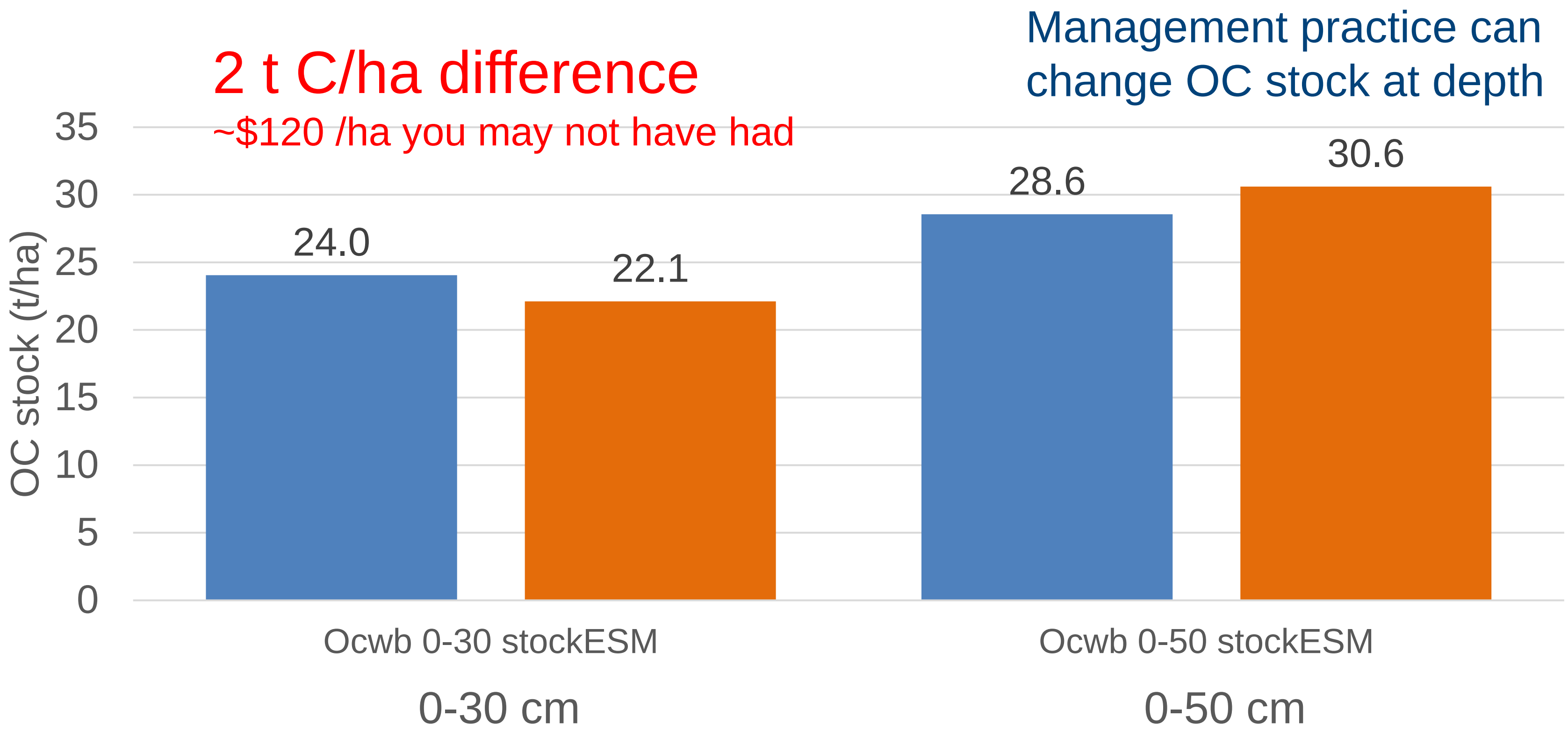
Coomandook (2022) – CTLAP C Project & MLA

15 t C/ha difference hill to flat





Soil depth



LANDSCAPE SOUTH AUSTRALIA
MURRAYLANDS AND RIVERLAND

Accumulating or Maintaining OC

Opportunity to increase soil OC depends on

OC inputs are more than the OC outputs (decomposition / erosion)

- Ability of soil to stabilise OC (texture, mineralogy)
- Capacity of the soil to store more OC (check the benchmarks)
- Understand limitations, is the soil functioning?
- Ability to grow and maintain sufficient biomass
- Sufficient nutrition to grown biomass and enable POC to HOC
- OC pools in the soil – longevity in humus-like pool

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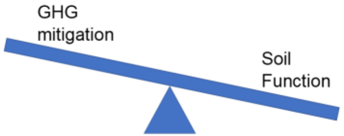
Take Home Thoughts

Determine why you want to change OC

- trade-offs for function if focus on GHG mitigation



Be realistic about how much you can change OC

- texture, rainfall, inherent limitations, induced limitations, fertility

OC is variable and needs a long time (5-10yrs) to measure change

- at the surface, down the soil profile, over time

Select management practices to build OC that

- suit your soil, climate and system

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My 2 cents worth

- Higher rainfall could have risk of declining soil OC in warmer climate
  - Indication this is already occurring
  - Change of system from pasture to cropping, increased microbial activity
- Sandy soils hardest to accumulate OC long-term
  - Most vulnerable as difficult to protect from decomposition
  - Change of particulate to humus like form if get greater inputs????
- Rainfall < 600mm can we build OC?
  - Rainfall <400 - 450mm and warm temperatures -aim to maintain OC
- How to change decomposition losses from 90 to 70%
  - Microbes – functional groups?

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How to build soil OC

- **Minimise C losses**
  cultivation practices, grazing management, retention of residues
- **Keep cover on your soil as long as possible**
  Think species mixes and diversity
- **Maximise OM inputs**
  Grow as much biomass above and below ground (grow roots deeper)
  Address soil constraints to production – pH, compaction etc
  Nutrition targeted to production
  Grazing management to encourage root exudates
- **Ensure practices are profitable and sustainable**
- **Learn and adapt as new information comes along**

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The theory of OC increase by management

Perennial pasture

Annual pasture

Adequate nutrition

Address soil limitations

Timely sowing

Stubble retention

Min or No tillage

Tillage

Bare soil

Cultivation

Add external sources of carbon

Maximise crop rotations

Maximise species mix

Maximise water use efficiency

Maximise productivity

CROPPING → PASTURE

OC stock by management practice

Management practices had variable effect on soil C

Abbreviations: P = Pasture, A = Annual, K = Kikuyu, C = Crop (no till, stubble retention).

How do you measure soil function?

Biomass / Productivity

Aim to: increase production whilst maintaining the soil resource

Most common measures undertaken

- Crop yield
- Pasture cuts / dry matter

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Nutrient cycling

Aim to: improve nutrient cycling and amount available to plants

Second most common measure undertaken

- Plant tissue or sap tests
- Soil tests

pH	Trace elements
Available N, P, K,S	Iron, Aluminium
Col P – PBI, DGT-P	Toxicities B, Na etc
Total N, P	Salinity
Exch cations; Ca, Mg, K, Na	Enzyme tests (P, Chitinase..)
Cation exchange capacity	**OC**

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Soil C tests

CO_3 = carbonate

Test	Method	Measures	Benefits/Limitations
Organic C	Wet oxidation (Walkley Black method)	OC	Incomplete reaction – measures 75-90% of Total OC. Doesn't measure CO_3 which can be a benefit.
Total C	High temperature combustion (Dumas)	OC & IC	Measures Total OC in acid or neutral soils. In soils with CO_3 and charcoal can be difficult to measure change in OC
Total Organic C	Acid pre-treatment then high temperature combustion	OC	Preferred method for soils with CO_3 present. Need to ensure that have complete removal of CO_3 before combustion or results will be incorrect.
Mid Infrared	Spectroscopy	OC and fractions	Quick and relatively cheap, not as accurate as other methods until calibrated. Sensitive to CO_3 and requires acid pretreatment. Not commercially available in high pH soil.
Labile C	Potassium permanganate	(P)OC	Measures energy source used by microbes. Sensitive to changes in soil health and fertility due to management. No Australian standards
Haney C	Water extractable	(P)OC	Measures energy source used by microbes. Not sufficient data in Australia for standards.

Water Cycle - Structural / physical options

Test type	Method	Measures	Pros / Cons
Visual assessment	Ground cover Soil texture, colour Topsoil depth, root depth and health Soil structure	Plant cover Soil capacity	Inexpensive and easily established. Repeat assessments need to be conducted at the same time/conditions Photos are incredibly useful for comparison over time
Water infiltration	Ring (pvc or steel) gently knocked into soil (~5cm), known volume of water added and time measured	Rate of water movement into the soil	Simple and effective test. Recommend repeating 2-3 times to get a steady state. Added value if use ruler to record water level at regular intervals.
Soil strength	Penetrometer or piece of hard wire	Force required to overcome resistance	A good tool if measured when soil moist (drained upper limit) otherwise just measuring the wetting front or texture change.
Bulk density	Collect a soil sample at specified depth of a known volume (eg exhaust pipe)	Soil mass / volume	Used to convert concentration to stock. Not a sensitive test
Slaking and dispersion	Drop pea sized crumbs of soil in bowl of rain or distilled water	Soil stability and sodicity	Simple test to assess aggregate stability

Species biodiversity options

Test type	Method	Measures	Pros / Cons
Visual assessment on farm	Earthworm, mites, springtails, spiders, ants etc	Species abundance and diversity	Inexpensive and easily established However, rainfall and time of the year can affect when species are active. Repeat assessments need to be conducted at the same time/conditions
With soil test	Soil OC Labile carbon Potentially mineralisable nitrogen	OC, PMN	Relatively inexpensive Conducted on same soil sample as other chemical analysis
Biological activity	Microbial biomass C and N Basal (CO_2) respiration	MBC, MBN Microbial activity	Relatively inexpensive
Biological diversity	Enzyme assays PLFA assessment	eg cellulose, phosphatase What is there	Relatively inexpensive
	Direct microscopy - species groups DNA tests – soil microbiome, bacteria, fungi, genes, pathogens eg Predicta B	eg bacteria, fungi, nematodes Fungi:bacteria	Abundance. Lots of detail. Functional groups important More expensive than other tests. Likely to need specialised sampling.

Adapted from Helen Hayden

Potential measures to assess soil function

Interest	How to measure
Soil texture, rootzone depth	Digging a hole – visual assessment
Chemical limitations for function	pH, salinity, sodicity, Ca:Mg ratio
Physical limitations for function	bulk density, soil strength, structure assessment, visual pans/compaction, water infiltration rate
Biological diversity	Species abundance, Functional groups, PLFA assessment, Fungal:Bacterial ratio
Biological activity	Basal respiration
Nutrient storage	Soil texture, cation exchange capacity (CEC)
Water storage	Texture, rootzone depth, bulk density, slope, gravel, water infiltration, structure assessment
SOC persistence	C fractions, TOC, Labile C
Nutrient cycling	Chemical analysis (Traditional, Haney), Available:Total N & P,
Biomass productivity	Dry matter or yield t/ha
Livestock productivity	Kg liveweight/ha (can also be reported on a kg/ha/100mm)

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5 step health check for agricultural soils

DEFINE what soil health is for the situation

1. IDENTIFY the soil type and its limitations
2. UNDERSTAND what can be changed and what can't
3. MODIFY the expectation, management practice or soil
4. MONITOR key soil, plant and economic attributes to measure soil health
5. REASSESS your system – is it working?

References


A Health Check for our Agricultural Soils

Soils are essential for food production, with 95% of food grown in association with soil. By 2050, it is estimated that agricultural production must increase globally by 60%, just to meet food demand (FAO 2015). With global population growth and increasing competition for land and water resources, there is a need to increase the health and productivity of soils that are available for agriculture. In the past, increasing food production has led to a decline in soil health with an estimated two thirds of Australian agricultural soils deemed to have one or more physical, chemical or biological limitation affecting soil health. However, we have learnt from the past and have a better understanding of sustainable soil management for improved productivity. Understanding your soils, their key limitations, and the feasibility of overcoming these limitations will determine if you can improve soil health and productivity to create a more profitable farm.

"Agriculture will only survive in the long term if soils are managed in ways that not only repair historical damage but also improve their physical, chemical and biological properties." [1]

What is Soil Health

Soil health is the ability of the soil to function as a living ecosystem in relation to its natural capacity. A healthy soil sustains biological productivity, maintains environmental quality, promotes plant, animal and human health, and is resilient and profitable.

A healthy soil has many functions (Table 1). The specific definition of a healthy soil used in agriculture will be different from that of a healthy soil in a natural ecosystem. Even within agriculture, there will be different requirements for dryland wheat compared to pasture soil for a grazier and it needs to be understood that soil health is relative to the system of production and the inherent natural properties of the particular soil.

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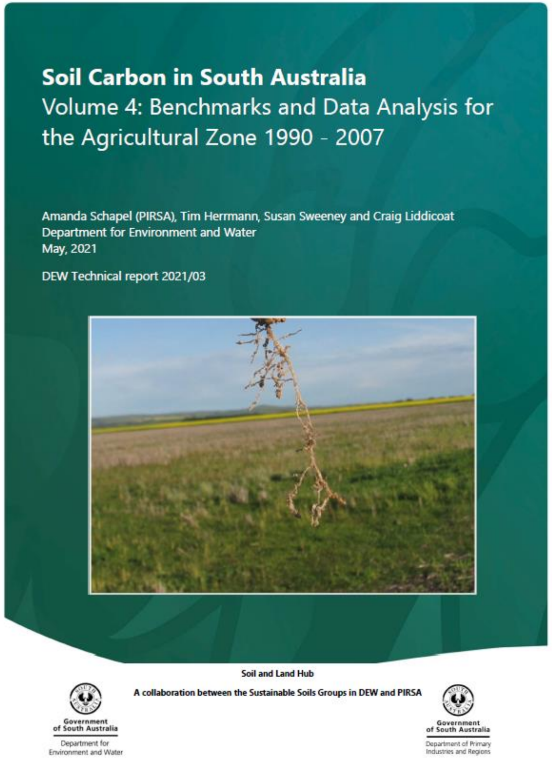

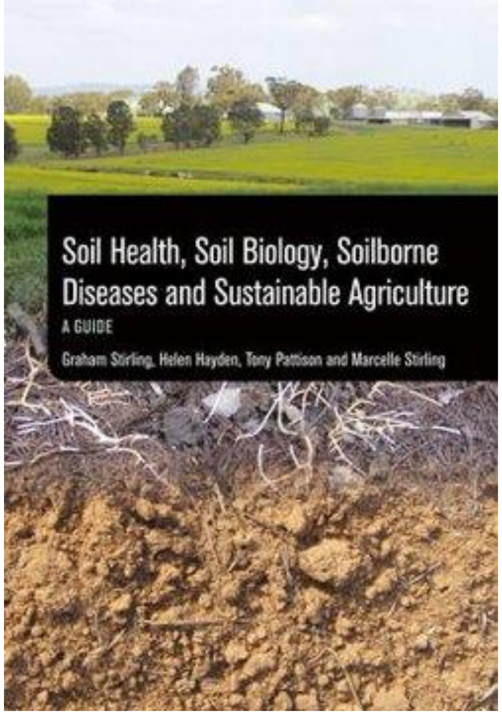

[Land Resources Home (environment.sa.gov.au) look under All Reports for Soil Health Factsheet and Soil C in SA Volume 4](http://environment.sa.gov.au)

Detailed info on biology tests: http://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/soilhealth_biology_tests

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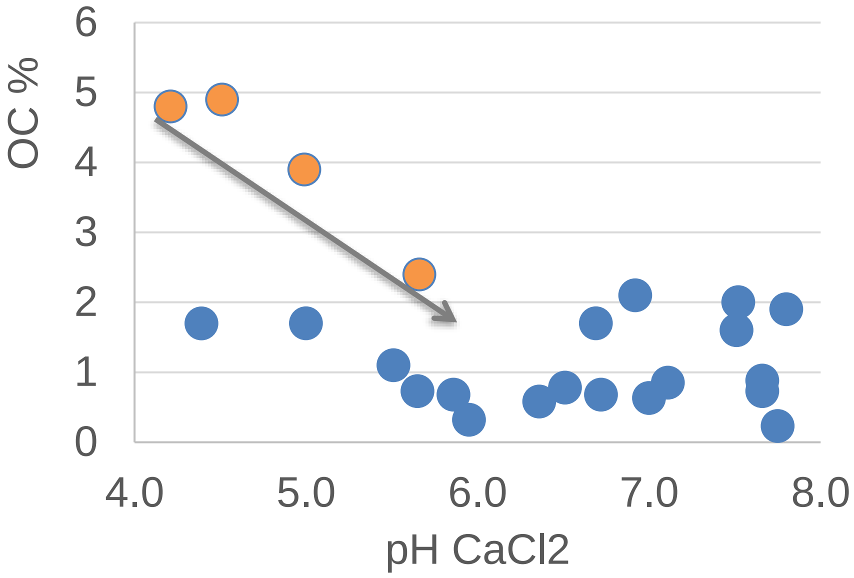
Adverse soil conditions can falsely increase OC



Saline black clay over calcrete

Depth (cm)	pH H_2O	pH $CaCl_2$	NO3 mg/kg	EC 1:5 dS/m	ECe	OC %
0-10	9.2	8.5	5.4	0.82	7	3.99
10-20	9.6	8.7	1.5	0.84	7	1.05
20-28	9.6	8.7	1.3	0.85	13	0.52
28-55	9.7	9.0	<1	0.78	12	0.06

Sand over clay with increasing lime

Depth (cm)	pH H_2O	pH $CaCl_2$	NO3 mg/kg	EC 1:5 dS/m	ECe	OC %
0-10	8.1	7.5	12	0.14	2	1.02
10-19	9.0	8.3	1.4	0.094	1	0.16
19-32	9.6	9.0	1.8	0.83	7	0.35
32-48	9.4	8.9	3	2.1	32	0.37

A non-functioning soil decreases biological activity