THE SCIENCE OF SOILS

How to optimise soil health for system benefits

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OVERVIEW

- What is a healthy soil?
- Key parameters that we can influence (physical and chemical)
- What is the most limiting factor in the system?
- What does this mean for soil carbon?
- If you don’t measure it, you can’t manage it – soil testing

WHAT IS A HEALTHY SOIL?

Three components of a healthy soil:

- Good physical condition
- Adequate chemical conditions
- Diverse microbial community

** The soil physical and chemical properties set the conditions within which microbes function…

… in turn, increased microbial activity can enhance physical condition, but cannot change soil chemical properties.

So what do those conditions look like?

WHAT ARE THE KEY SOIL PHYSICAL CONSTRAINTS?

1. **Soil type and clay content**
   - Increasing clay content means greater capacity for structure and water storage than a sandy soil
   - But, greater potential for pugging heavier soils due to stock movement under consistently wet conditions, which reduces water and air movement into the soil
   - If soils have a history of pugging and with poor growth response to rainfall and nutrition, might need strategic (and smart) cultivation to remove compaction layers, aligned with pasture reseeding
     - (align with lime application if needed)

Photo: Agriculture Victoria

WHAT ARE THE KEY SOIL PHYSICAL CONSTRAINTS?

2. Sodicity / dispersion

- High levels of exchangeable sodium within the clay matrix
- Causes dispersion in wet conditions, which is a breakdown of soil structure into individual clay particles
- Causes surface crusting and poor water infiltration
- Indicated by the ‘Exchangeable sodium percentage (ESP)’ on soil tests – a chemical measure with physical impact
- Gypsum can be of value through reducing ESP by replacing sodium with calcium

3. Slaking

- Breakdown of soil aggregates into micro-aggregates upon surface exposure to water
- Slaking soils should not be deep ripped
- Deep cultivation will cause poor trafficability, plan ahead if doing ‘remediation cultivation’

Both of these factors contribute to compaction – understand system before addressing compaction

WHAT DOES THIS MEAN?

Soil microbes (and worms etc) need oxygen and water to function.

Compacted, dispersive and crusting soils reduce the capacity for water and oxygen.

Easy to tell if soils have turned anaerobic (low oxygen) – they smell bad and ‘ooze’ when wet.

Set up (and protect) soil conditions to enhance water and oxygen movement, which in turn will stimulate soil biota (worms, fungi, bacteria)

… which will bring further benefit to the soil system

WHAT ARE THE KEY SOIL CHEMICAL CONSTRAINTS?

1. Soil pH
2. Soil fertility / nutrition
3. Low organic matter (soil carbon)

Key consideration:

Undisturbed native systems are sustainable cycles whereby all plant material is recycled at the point of growth.

All agricultural activities rely on product removal.

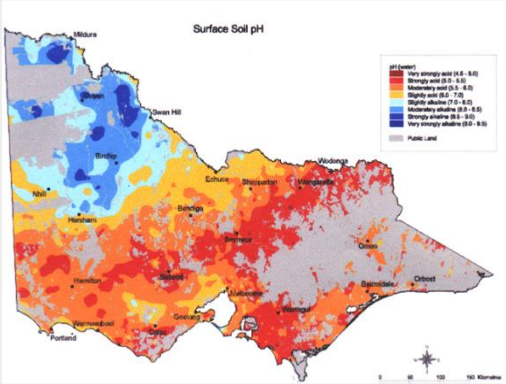
All food/fibre/forage products remove nutrients and alkali (net high pH) off-site.

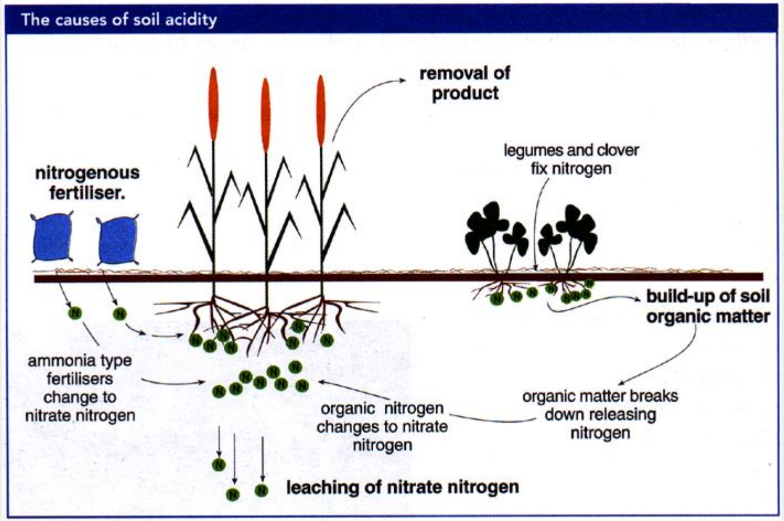
A *sustainable agricultural system* requires those exported products to be replaced. If not, the system is being exploited and mined.

SOIL ACIDITY / SOIL pH

An increase in acidity (decreased pH) is due to:

- Increased productivity and export (milk, hay, grain, beef)
- Nitrogen addition (urea and legume)





Removal of 1 tonne of lucerne hay requires 60 kg of lime to balance out the pH

SURFACE & SUBSURFACE ACIDITY

- Most lime is surface broadcast
- Lime is only poorly soluble
- Lime rates are generally inadequate for current rates of acidification
- *Rules of thumb* lime rates established under cultivated systems with greater mixing of soil layers

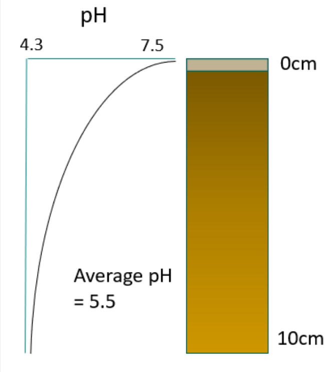
- Broadcast lime + low rates = increased acidification at depth

- Apply lime to target pH 5.8 (so lime can move down for amelioration of subsoil pH)

  => Incorporate

  => Hands off, and monitor until lime needed again (5-7yrs)

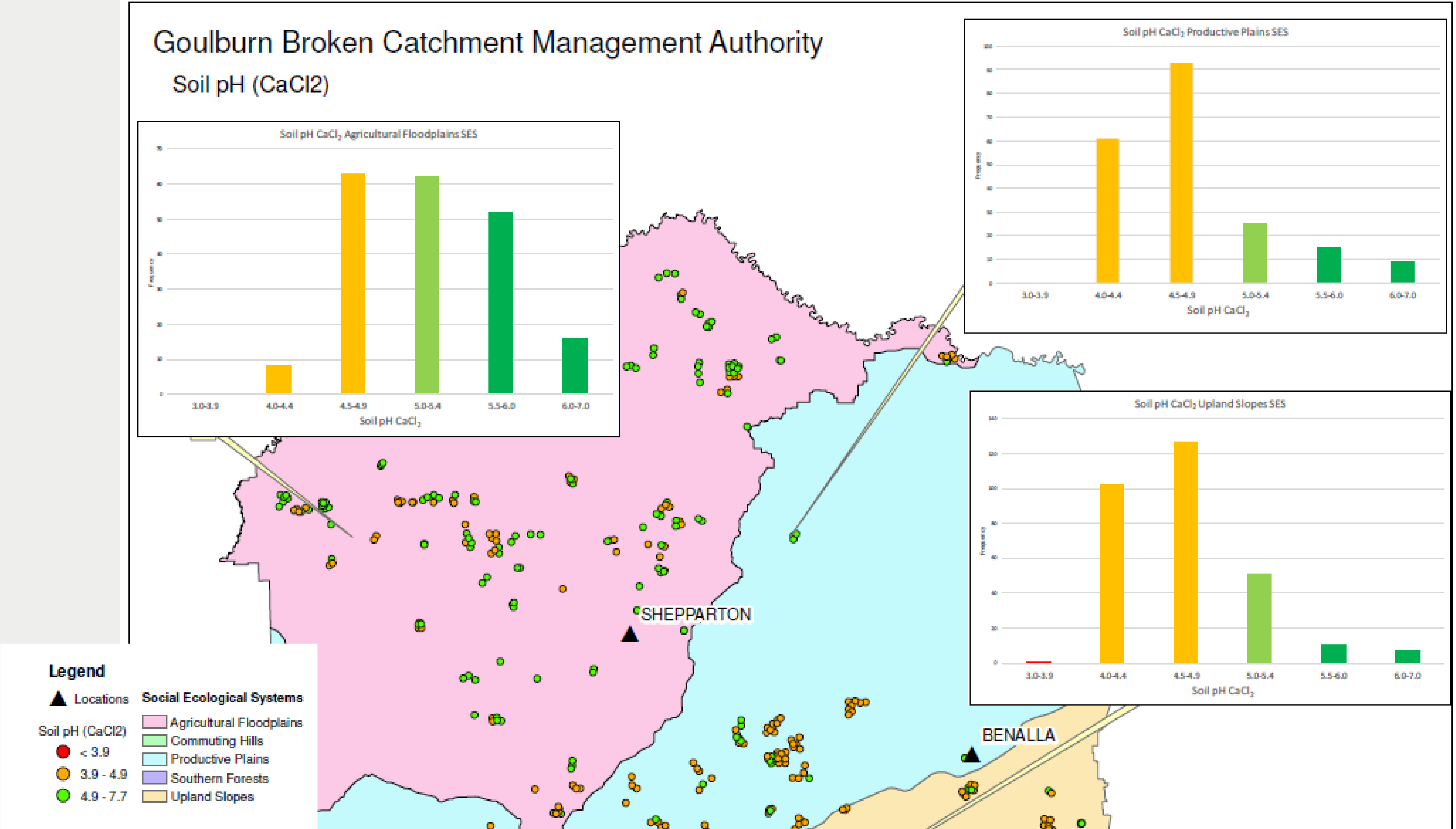
** Don't 'fairy dust' the lime, cover less ground per year, using higher lime rates



0-5cm pH 4.4

5-10cm pH 4.0

10-20cm pH 4.1



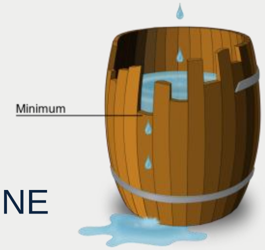
Goulburn Broken Catchment Management Authority
Soil pH (CaCl2)
Soil pH $CaCl_2$ Agricultural Floodplains SES
3.0-3.9
4.0-4.4
4.5-4.9
5.0-5.4
5.5-6.0
6.0-7.0
Soil pH $CaCl_2$
Soil pH $CaCl_2$ Productive Plains SES
3.0-3.9
4.0-4.4
4.5-4.9
5.0-5.4
5.5-6.0
6.0-7.0
Soil pH $CaCl_2$
Soil pH $CaCl_2$ Upland Slopes SES
3.0-3.9
4.0-4.4
4.5-4.9
5.0-5.4
5.5-6.0
6.0-7.0
Soil pH $CaCl_2$
SHEPPARTON
BENALLA
Legend
Locations
Soil pH (CaCl2)
< 3.9
3.9 - 4.9
4.9 - 7.7
Social Ecological Systems
Agricultural Floodplains
Commuting Hills
Productive Plains
Southern Forests
Upland Slopes

CLUES FOR ACIDITY – SURFACE & SUBSURFACE

- Farming in NE Victoria – acidity is very common
- Acidity coming through in previously highly productive zones (high alkali export), that are running out of steam
- ‘May’ be the lower CEC zone with lighter soils
- Poor crop establishment or poor lucerne vigour
- (Check nodulation)
- Higher soil organic carbon values can ‘mask’ Al, don’t rely on visual Al toxicity
- Lack of historical sampling >10cm depth
- A drop in CEC in the 10-20cm zone strongly aligned with susceptibility to subsoil acidity in lighter textured soils
- BUT surface & subsoil acidity can also affect heavier soils

	Depth (cm)	pH Ca	CEC cmol(+)/kg
Rutherglen	0-10	5.1	3.93
	10-20	**4.3**	**2.1**
	20-30	**4.2**	**3.01**
Boorhaman	0-10	**4.8**	7.6
	10-20	**4.3**	**4.7**
	20-30	**4.4**	**6.9**
Jerilderie	0-10	**4.7**	15.8
	10-20	**4.6**	15.7
	20-30	4.9	15.9

SOIL pH, NUTRIENTS AND PRODUCTION



Liebig's law of the minimum

Soil pH and soil acidity is generally the most limiting factor in plant growth in NE Victoria

Many plant species cannot grow well and persist at low pH values

Many nutrients are less available

- P, N, K, S, Ca, Mn, Mo

Poor plant growth response to applied fertilisers

Reduced microbial function

- Poor Rhizobium inoculation of legumes, poor persistence of lucerne stands
- Poor nitrogen mineralisation from organic matter

****Once pH is increased through liming, ensure other soil conditions aren't limiting plant growth**

… such as nutrition and soil fertility

NUTRITION FOR ANIMALS, GRASS AND MICROBES

Many of the nutrition recommendations for cropping and pasture are becoming outdated:

1.

New pasture and crop varieties + current agronomy + greater intensity

= means that many nutrients are becoming depleted

2.

Nutrition response trials were done in fully mixed systems (cultivated) which assume a uniform distribution of nutrients within topsoil.

No-till cropping and drill sown pastures means that little soil mixing occurs (nutrients are concentrated on surface, beyond rooting range)

= Likelihood that soil tests are not picking up deficiencies, so rates are not high enough

Common deficiencies in Murray region: P, K, S, Mo, (N in non-legume &or acid soils)

NUTRITION FOR ANIMALS, GRASS AND MICROBES

Supplying adequate nutrients is a **win – win – win**

What is good for animal nutrition is good for plant growth is good for soil microbes.

Just like animals and plants, microbes need a balanced diet. If they don’t have access to the nutrients they need, they can’t perform their functions well.

*** Some microbes can capture N from the atmosphere (diazotrophs such as *Rhizobia* and other free-living N fixers)

*** Other microbes can access soil nutrient reserves (eg P) through enzymes such as *phosphatases*, but they cannot ‘create’ P or other nutrients.

As all Murray valley soils (and most Australian soils) are low in total P, S and K, plant and microbial extraction of these nutrients is mining the soil. It must be replaced in order to be *sustainable*.

WHAT DOES THIS MEAN FOR SOIL CARBON?

Soil organic matter in its broadest sense, encompasses all of the organic materials found in soils regardless of origin or state of decomposition.

Soil organic matter has a consistent ratio of nutrients:

- C:N = 10:1
- C:S = 54:1 (subject to key microbes present)
- $C:P_{org}$ = 155:1 (subject to minerals present)

Kirkby et al (2011) *Geoderma*

[Humus – scientific definition is ‘*the fine fraction of SOM which passes through a 53μm sieve, mostly bound to clay minerals*’]

Soil organic carbon (%) x 1.72 = SOM (%)

Recent review: Murphy, B, W, (2014) Soil Organic Matter and Soil Function – Review of the Literature and Underlying Data. Department of the Environment, Canberra, Australia.

ROLE OF MICROBES IN SOIL CARBON

- Capture of atmospheric CO_2 into plants through photosynthesis, which uses light energy to convert CO_2 into carbohydrates in plant leaves:
  - CO_2 + water => glucose + oxygen + water [$6CO_2 + 6H_2O \Rightarrow C_6H_{12}O_6 + 6O_2$]
- Microbes decompose plant litter, breaking down into soil organic matter
- Microbes die and are decomposed by other microbes, building carbon
- If there is a net accumulation of carbon through this process, carbon from the atmosphere is captured, or 'sequestered' into soil

Microbes breathe out CO_2, nitrous oxide and other GHG's

Not a perfect process

KEY CONSTRAINTS IN SOIL CARBON ACCRUAL

1. Soil pH

- Optimised soil biology requires a diversity of microbial types and species
- Not many species can flourish under acidic soils, limiting diversity and selecting for less beneficial species.
- Nutrient cycling and release from SOM is inhibited in acid soils, reducing the contribution of SOM to nutrient availability

Figure 6 Well nodulated (left) compared to poorly nodulated subclover plants (right). Photo: Centre for Rhizobium Studies, Murdoch University

2. Nutrient availability

- Imbalance of nutrients, such as lack of N

=> more C lost as CO_2

=> poor conversion to SOM

Table 2: Maximum, minimum, and optimum pH values for microbial groups. (adapted from Smith and Doran 1996)

Microorganisms	Range	Optimum
Bacteria	5 - 9	7
Actinomycetes	6.5 - 9.5	8
Fungi	2 - 7	5
Blue green bacteria	6 - 9	> 7
Protozoa	5 - 8	> 7

http://soilquality.org/indicators/soil_ph.html

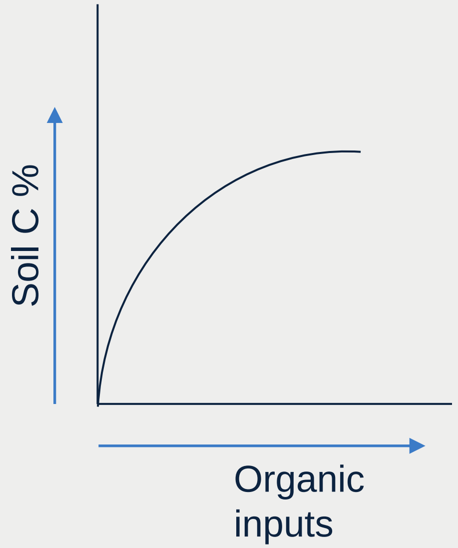
LIMITATIONS ON SOIL CARBON WITHIN THE MURRAY REGION

- Sandy soils can 'hold' less carbon than clay soils due to less surface area and less exchange capacity (chemical binding sites)
- Low pH soils can retain less carbon, with less microbial function
- Crusted, dispersive or compacted soils will require amelioration to build more carbon

Address key limitations before focussing on soil C accrual

- Each soil has a threshold C capacity – not an ongoing linear increase

- Soils in tropical/subtropical regions can build more carbon due to moist, warm soils with a high biological capacity



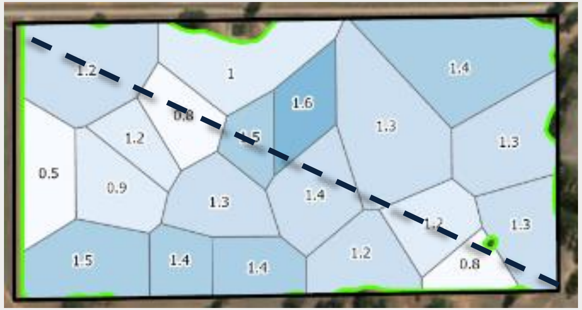
IF YOU DON'T MEASURE IT, YOU CAN'T MANAGE IT
TRANSECT vs GPS SAMPLING

Transect sampling involves collecting soil from across the paddock and bulking together into the same bucket, and taking a subsample for analysis.

= *average of paddock (with lots of 'in-built' variance)*

=> incredibly difficult to detect SOC change over time as each zone will change at a different rate.

So, likelihood of no real change in SOC measurable over time

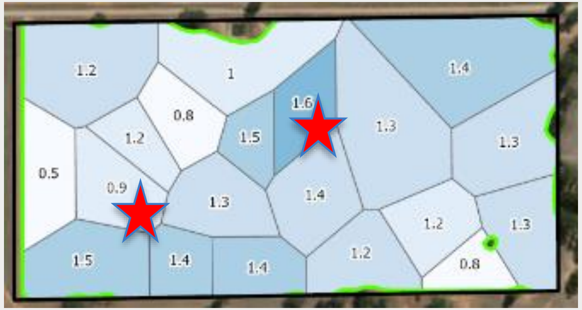


GPS located sampling involves collecting soil from one (or several) specific locations in the paddock, kept separate for analysis.

If from different soil types, indicates range in SOC across paddock.

= *more accurate value at a certain location*

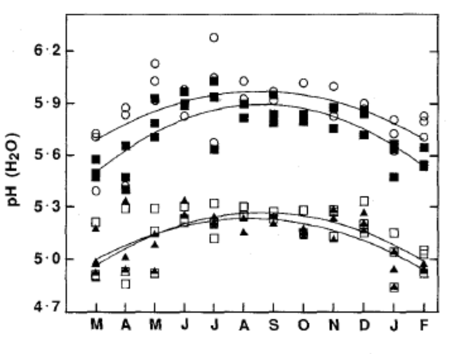
=> greater chance of tracking change over time.

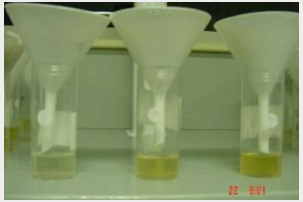


**** Depth incremented sampling down to 30 or 60cm provides a good long-term baseline from which to monitor soil nutrients, constraints and carbon.**

GENERAL COMMENTS ON SOIL TESTING

- Chose GPS sampling points based on the *best* and *worst* performing areas in the paddock (or elevation / visual soil change / waterlogging etc)
- Record GPS points for return sampling
- Use a standard method of sampling (record number of samples/site etc, soil sampler vs shovel)
- Sample at the same time of year under non-saturated conditions
- Keep samples cool until sending to lab via Express Post
- Use a NATA accredited laboratory, preferably also ASPAC accredited
- Use the same lab & same test every time
- Soil analyses for microbial communities are subject to high variability (time and space)
- Sampling for net increases in soil carbon stocks (sequestration) for carbon credits requires adherence to strict protocols





SUMMARY

A focus on improving the physical and chemical condition of the soil will result in improved soil biology, with system benefits.

Soil carbon, microbial activity and plant growth are all constrained by the '*most limiting factor*' in the system, if you don't address that, all other efforts are of limited value.

If you don't measure it, you can't manage it: Accurate soil testing is key to understanding your baseline and monitoring change.

Finally: Dig a hole!

Soil pits are a great way to look at rooting depth, physical soil constraints, water availability and soil texture changes with depth.

Thank you!

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