Soil quality and health in pasture systems

Key points

- Organism diversity, groundcover, root depth, organic carbon and aggregate stability were all at levels of a 'healthy soil'
- Soil pH, microbial activity, sub clover nodulation and earthworm numbers were at less-than-ideal levels
- Soil acidity is a major soil constraint in our region and is likely to be one of the main drivers of reduced microbial activity in our region's soils
- An increase in microbial activity was strongly correlated with an increase in soil organic carbon, labile carbon and/or total nitrogen.
- The soil biology laboratory tests used in the project provided a good insight into the diversity and abundance of soil microbes but are unlikely to assist pasture management decisions.

Introduction

The aim of the 'Soil quality and health in pasture systems' project, funded by the Australian Government's National Landcare Program, was to develop benchmark and extension information on the quality and health of our local soils. One component of the project was to create a soil health snapshot of the region's main soil types, farming systems and rainfall zones through soil sampling and analysis of Holbrook Landcare Network's (HLN) soils database. This will assist managers of permanent pastures and achieve better outcomes for groundcover, soil health and productivity.

This project is a follow on from several soil monitoring projects conducted in the region by HLN since 2017 and the sample sites established in this project have contributed to HLN's long-term soil monitoring site network.

It's important to note that this project provides a snapshot only of the health of the regions different soil types, farming systems and rainfall zones, due to the small number of sample points. Significantly more sample points, requiring significantly more funding, is needed to undertake a comprehensive comparison of soil health between the different farming systems and rainfall zones.

Methodology

A total of 16 pasture paddock sites were chosen across the region (from Gerogery in the west to Tumbarumba in the east) on representative soil types, farming systems and rainfall zones. Geology mapping, soil landscape mapping, and local knowledge was used to identify representative soil types across the region. Some of the 16 sites were existing soil monitoring sites established by HLN in recent years and existing soil data was used where possible. The 16 sites were within:

- 4 different farming systems:
    - Improved pasture with high fertiliser history (n=5)
    - Improved pasture with low fertiliser history (n=4)
    - Native pasture with no fertiliser history (n=4)
    - Multi-species pasture with various fertiliser histories (n=3)

- 3 rainfall zones:
    - <600 mm (n=6)
    - 600-800 mm (n=6)
    - >800 mm (n=4)

- 6 soil types:
    - Brown, Red or Yellow Kurosol (n=4)
    - Brown Sodosol (n=1)
    - Brown or Red Chromosol (n=3)
    - Brown or Red Dermosol (n=3)
    - Brown or Red Kandosol (n=3)
    - Brown-Orthic Tenesol (n=2)

The soil sampling was completed in two stages. In mid-August 2021, topsoil 0-10cm samples were collected using a 20mm diameter foot probe (20-30 cores per site) and sent to Microbiology Laboratories Australia and Soil Foodweb Institute for microbiology testing, and Environmental Analysis Laboratory (EAL) for total nitrogen and labile carbon (see Appendix 1 for details). Field measures of biological and physical health (listed in Appendix 1) were also measured during the first stage.

The sites were revisited approximately 60 days later (mid-October 2021) for the second stage. The undies were dug out of the ground and assessed for level of decomposition, and surface and subsurface soil samples were collected using a 28 mm diameter core tube (20 cores per site) and bulked for 0 – 5, 5 – 10, 10 – 15, 15 – 20 and 20 – 30 cm depth intervals. The samples were sent to CSBP Soil and Plant Analysis Laboratory for chemical analysis. A small pit was dug to describe the soil (texture, colour, structure, gravels, horizon depth) according to the *Australian Soil and Land Survey Field Handbook*[1] and soil type was determined using *The Australian Soil Classification (ASC)*[2]. A list of these resources can be found at the end of this report.

Results and Discussion

A summary of the findings for each test method is presented in Table 1. Some of the important indicators and relationships are discussed in more detail below.

Table 1. Summary of the findings for each test measured in the project.

Test	Summary	Overall Rating
pH (CaCl2)	81% of sites were severely to moderately acidic in the subsurface layers (5-20cm). *See text below.*	Poor
Electrical conductivity	Salinity levels were low (<1.5 Ece) across all 16 sites	Very Good*
Phosphorus (Colwell)	Above critical values (>30 mg/kg)[3] at 56% of sites	Moderate
Sulfur (KCL 40)	Above critical values (>8 mg/kg)[4] at only 1 site	Poor
Exchangeable aluminium %	Severely acidic sites had 29% Exch Al% on average and moderately acidic sites had 16% Exch Al%. *See text below*	Poor
Exchangeable sodium % (ESP)	Sodic levels (ESP >6%)[5] in the subsurface of only 2 sites	Good*
Total organic carbon	2.9% average for all sites. Rainfall zone averages within 'normal' range for pastures[6]. *See text below.*	Good
Labile carbon	0.67% average for all sites.	N/A
Total nitrogen	Low (0.05-0.15 %)[7] at 4 sites, medium (0.15-0.25 %) at 6 sites and high (0.25-0.50 %) at 6 sites	Moderate
Total bacteria	At desired levels (175-300 µg/g) at only 2 sites	Poor
Total fungi	Below desirable levels (175-300 µg/g) at all sites	Poor
Soil basal respiration	Levels good at 4 sites (>460 mgC0₂/kg/day), and moderate (150-460 mgC0₂/kg/day) at 12 sites. *See text below*	Moderate
'Soil Your Undies'	Minimal decomposition at all sites. *See text below*	Poor
Sub clover nodulation	Average score of 3.2. *See text below*	Poor
Soil organism count	Very good (>5 types)[8] at 9 sites, good (3-5 types) at 4 sites, and moderate (1-2 types) at 3 sites.	Good
Earthworm count	94% of sites had low counts (<10 worms/square)[9].	Poor
Root depth	Very good (>15 roots at 20cm)[10] at all sites	Very Good
Groundcover %	Very good (>90%)[10] at 13 sites	Good
Infiltration	Poor (<25mm/hr)[8] at 3 sites, Moderate (25-100mm/hr) at 7 sites, Good (100-250mm/hr) at 4 sites, and Very Good (>250mm/hr) at 2 sites.	Moderate
Aggregate Stability (slaking and dispersion)	Slaking was Good (slight slaking)[8] at 0-10cm and Moderate (20-70% slaking) at 10-20cm on average for all sites. Dispersion was Very Good (Nil dispersion) at 0-10cm and Good (slight dispersion) at 10-20cm on average.	Good

* Salinity and sodicity is known to occur in the region

Soil acidity and exchangeable aluminium

Soil pH is critical to plant and soil microbe health, and soil function. Low pH reduces the productive potential of many crop and pasture species by reducing root growth and altering the availability and the plants' ability to access nutrients and water. Most soil microbes and nitrogen fixing rhizobia require higher pH environments to survive and function. As pH declines some nutrients become unavailable to plants, such as phosphorus and molybdenum, while other elements, such as aluminium and manganese can reach toxic levels. The ideal target soil pH for most plant species is pH_{Ca} > 5.5 throughout the root zone, but particularly in the 0 – 20 cm surface layers, where up to 80% of the roots of most annual species are concentrated.

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Aluminium becomes available in the soil solution when soil pH_{Ca} is below 5.2 and increases rapidly in many soils as pH_{Ca} falls below 4.8. Aluminium stunts the root system, reduces root density and limits root hair development, minimising access to water and nutrients (P, K and Mg). Both low pH and levels of exchangeable aluminium as low as 2% can reduce nodulation and nitrogen fixation by legumes.

Analysis of the 16 sites showed that 25% of sites were severely acidic (pH_{Ca} <4.5) in the subsurface layers (5-20cm), 56% were moderately acidic (pH_{Ca} 4.5-5), and 19% were slightly acidic (pH_{Ca} >5). The sites that were severely acidic (pH_{Ca} <4.5) had 29% exchangeable aluminium on average in the subsurface layers (5-20cm). The sites that were moderately acidic (pH_{Ca} 4.5-5) had 16% exchangeable aluminium on average, and the sites that were slightly acidic (pH_{Ca} >5) had an average of 2% exchangeable aluminium.

Organic carbon (OC)

Soil organic carbon (OC) is the carbon component of soil organic matter, with more than 50% concentrated in the shallow surface soil (0 – 5 cm). It is important for nutrient availability to plants, soil structure, and soil biological function. Soil OC levels are generally greater in higher rainfall areas due to increased plant growth, soil moisture and biological activity. Therefore, location needs to be taken into account when evaluating whether soil carbon values are high or low.

Organic carbon (OC) in the surface 10cm for all sites averaged 2.9% and ranged between 1.5% and 5.4%. Average OC was 2.3% in the <600 mm rainfall zone (range 1.5 - 3.2%), 2.9% in the 600 – 800 mm zone (range 1.9 - 3.6%), and 3.9% in the >800 mm zone (range 1.8 – 5.4%). Average OC levels in each rainfall zone were in the 'normal' range for pastures (see Resource list no. 6 for more information).

Labile carbon

Labile carbon is the portion of soil organic carbon available as an energy source to soil microbes. It decomposes or 'turns over' relatively rapidly (<5 years) compared to other more stable forms of soil organic carbon that can take years or centuries to decompose. Labile carbon influences both the activity and mass of soil microbes (microbial biomass) and supports the formation of soil aggregates that improve soil structure. Since labile carbon turns over relatively rapidly, it is considered a more sensitive indicator of changes in soil quality and function than soil organic carbon which includes the more stable fractions. There are no 'ideal' values for labile carbon but in general, the higher the better. Monitoring levels over time can be a good indicator of likely soil microbial activity levels.

Labile carbon levels averaged 0.67% and ranged between 0.3% and 1.4%. On average, labile carbon levels were 23% of the soil organic carbon levels. The sites with the highest labile carbon levels were in the high rainfall zone.

Total nitrogen

Total nitrogen is the total amount of nitrogen present in the soil as a percentage by weight. Nitrogen is an essential nutrient for plant growth and occurs in the soil in several forms. Organic nitrogen, which makes up 98% of the soil pool is converted to plant available nitrate or ammonia by soil microbes through a process called mineralisation.

Total soil nitrogen levels ranged between 0.12% to 0.47%. Levels were low (0.05-0.15 %) at 4 of the 16 sites, medium (0.15-0.25 %) at 6 sites, and high (0.25-0.50 %) at 6 sites. The sites with the highest total nitrogen levels were in the high rainfall zone.

Potential microbial activity

Soil microbes are the living component of organic matter and a responsible for decomposing organic residue and cycling and releasing nutrients. Soil basal respiration (rate of CO_2 respiration by microbes), soil microbial biomass carbon (the total mass of microbes), potentially mineralisable nitrogen (PMN) and potentially releasable phosphorus (PRP) assess the soil's capacity for total microbial activity and potential nutrient release under ideal conditions. In general, higher activity is link to better soil heath and nutrient availability.

Soil basal respiration levels were 'good' at four sites (>460 mgC02/kg/day), and 'fair' (150-460 mgC02/kg/day) at 12 sites. The four sites with 'good' levels were improved pasture paddocks with various fertiliser histories.

Soil Your Undies

The 'Soil Your Undies' test is used across Australia as a novel way to indicate the abundance and activity of soil microbes, specifically generalist feeding bacteria and fungi that break down plant materials in the same way. It involves burying cotton underpants in the top 5cm of soil and leaving in the ground for two months.

The level of undie decomposition was minimal over the two months for all sites. The most breakdown observed was at 2 sites that had one or two spots, about the size of a fingernail, where all the cotton was eaten away and just the elastane mesh left. Other sites had orange and blue coloured staining across 10-40% of the undie indicative of fungi and/or bacteria, but no breakdown as such.

The level of decomposition was significantly less than other parts of the country that experience complete undies decomposition. The lack of breakdown is consistent with the 'moderate' microbial activity measured (mentioned above) and could be due to several factors. Temperature and pH are two of the main factors that affect microbial activity and growth. The cooler than normal Spring of 2021 could have been a factor, and/or the moderate to severe levels of acidity in the topsoil (0-10 cm) at 75% of sites.

Sub clover nodulation

Sub clover can fix nitrogen gas from the atmosphere and convert into ammonia through a symbiotic relationship with Rhizobium bacteria. The general assumption is that a well nodulated sub clover plant fixes 20-30 kg N per tonne of above-ground dry matter that is produced. There are many factors that can potentially affect nodulation and N-fixation including, rhizobia specificity, soil texture, soil pH, soil fertility, certain herbicides, waterlogging, drought and seasonal timing. A plant that is not adequately fixing nitrogen from the atmosphere will be using nitrogen from the soil and not building it.

Thirteen of the 16 pasture paddocks contained sub clover and were assessed. The average nodulation score for the 13 sites was 3.2 and ranged between 2.3 and 4.0. The average nodulation score is below adequate levels (<4) and is similar to what was found in the 2017 'Sub Clover Nodule Health Project'.

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Relationships

A comparison between each soil property was made using a linear regression plot in Excel. Only moderate to strong (R^2 >0.4) relationships are presented below. Positive relationships were found between:

- Total organic carbon and total nitrogen (R^2=0.85)
- Total organic carbon and labile carbon (R^2=0.65)
- Total nitrogen and labile carbon (R^2=0.85)
- Total nitrogen and soil basal respiration, soil microbial biomass carbon, PMN, PRP (R^2=0.72)
- Labile carbon and soil basal respiration, soil microbial biomass carbon, PMN, PRP (R^2=0.72) and
- Total organic carbon and soil basal respiration, soil microbial biomass carbon, PMN, PRP (R^2=0.44)

This indicates that total organic carbon, labile carbon and total nitrogen levels increase with each other and that an increase in these properties generally leads to an increase in microbial activity.

Other positive relationships were found between:

- Organism diversity count and nodulation score (R^2=0.45)
- Organism diversity count and Fungi:Bacteria ratio (R^2=0.43)
- Rainfall zone and total nitrogen (R=0.43)*
- Rainfall zone and labile carbon (R=0.39)* and
- Rainfall zone and Fungi:Bacteria ratio (R=0.40)*

There were no relationships, of moderate or strong significance, found between farming systems and any of the measured soil properties.

Summary

The project found certain physical, chemical and biological properties were at desirable levels for a 'healthy soil' and other properties at levels of an 'unhealthy soil'. Organism diversity, groundcover, root depth, organic carbon and aggregate stability were all at good levels. Whereas, soil pH, microbial activity, sub clover nodulation and earthworm numbers were less than ideal. Soil acidity is a major soil constraint in our region and is likely to be one of the main drivers of reduced microbial activity in our region's soils.

Soil biology laboratory tests can be expensive and although they provide a great insight into the diversity and abundance of soil microbes, they appear to have limited use in guiding management decisions. At least the test tests used in this project anyway. The soil chemistry test results for this project identified soil organic carbon, labile carbon and total nitrogen were strongly correlated with microbial activity. Therefore, testing one or all these properties will give a cost effective and reasonable indication as to how the soil microbial community in your soil is performing. In other words, if your carbon and nitrogen levels are high, it's highly likely your soil microbial community will be active.

Soil organic carbon, labile carbon and total nitrogen are found in organic matter, so building soil organic matter in pasture systems is the key to increasing microbial activity and overall health of soils. The ways you can achieve this as a producer is by addressing soil constraints (e.g soil acidity) to maximise plant biomass production and through good grazing management. Good grazing management practices include maintaining groundcover and pasture dry matter/biomass all year round. Maintaining groundcover is essential for minimising erosion and maximising water infiltration, and for protecting the surface soil from heat and evaporation. It also provides a home and food source for soil biology. Leaving enough pasture dry matter/biomass all year round keeps roots in the ground that maintain soil function, soil organic matter and soil structure.

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Resources

1. Australian Soil and Land Survey Field Handbook https://www.publish.csiro.au/book/5230/
2. The Australian Soil Classification https://www.soilscienceaustralia.org.au/asc/soilhome.htm
3. MLA soil phosphorus tool https://www.mla.com.au/extension-training-and-tools/tools-calculators/phosphorus-tool/
4. Agriculture Victoria – understanding soil tests for pastures https://agriculture.vic.gov.au/farm-management/soil/understanding-soil-tests-for-pastures
5. Sodicity https://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/soil_soil-sodicity
6. Interpreting soil test results – what do all the numbers mean? https://catalogue.nla.gov.au/Record/3993850
7. Analytical methods and interpretations used by the Agicultural Chemistry Branch for soil and land use surveys https://catalogue.nla.gov.au/Record/1884520
8. NQ Dry Tropics Rapid Assessment of Soil Health (RASH) Manual https://www.nqdrytropics.com.au/rash/
9. Earthworms https://www.mla.com.au/globalassets/mla-corporate/extensions-training-and-tools/creative-commons/increasing-earthworms-in-pastures---cc.pdf
10. Landcare Rapid Assessment of Soil Health (RASH) Manual https://gmln.com.au/wp-content/uploads/2020/02/RASH-manual_web.pdf
11. Labile carbon testing method https://www.publish.csiro.au/cp/AR9951459
12. Soil Foodweb Institute https://www.soilfoodweb.com.au/our-services/price-list
13. CottonInfo – Soil Your Undies https://www.cottoninfo.com.au/soilyourundies
14. Sub clover nodulation scoring – Ron Yates scoring system https://www.mla.com.au/contentassets/ab149219e552408ab48ba9cc9eab833e/how-do-i-better-manage.pdf
15. Microbiology Laboratories Australia https://microbelabs.com.au/product/microbe-activity-wise-pro/

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Appendix 1 - List of chemical, biological and physical tests used in the project to measure soil health.

Test	Method	Cost (inc. GST)	Laboratory
Chemical Indicators			
pH ($CaCl_2$)	Rayment and Lyons Method 4B4, 4A1 and 3A1	$17.20	CSBP Plant and Soil Analysis Laboratory
pH (1:5 water)			
Electrical Conductivity (dS/m)			
Ammonium Nitrogen (mg/kg)	Rayment and Lyons Method 7C2b	$17.20	
Nitrate Nitrogen (mg/kg)			
Phosphorus (Colwell) (mg/kg)	Rayment and Lyons Method 9B and 18A1	$17.20	
Potassium (Colwell) (mg/kg)			
Sulfur (KCL 40) (mg/kg)	Rayment and Lyons Method 10D1	$17.20	
Exchangeable Cations without pre-wash (Al, Ca, Mg, K, Na) (meq/100g)	Rayment and Lyons Method 15E1	$17.20	
Total Organic Carbon (Acid Wash) (%)	Rayment and Lyons Method 6B3 (CFI approved method)	$33.80	
Labile Carbon (%)	Blair 1995 – 0.333M $KMnO_4$	$55/sample + admin fee	Environmental Analysis Laboratory (EAL)
Total Nitrogen (LECO) (%)	Inhouse S4a (LECO Trumac Analyser)		
Biological Indicators			
Total Bacteria (µg/g)	Direct Microscopic Count (DMC)	$43.00/sample	Soil Foodweb Institute
Total Fungi (µg/g)	Direct Microscopic Count (DMC)	$39.00/sample	Soil Foodweb Institute
Soil Basal Respiration (SBR) ($mgCO_2$/kg/day)	Soil microbe CO_2 production over 3 days	$99.00/sample	Microbiology Laboratories Australia
Soil Microbial Biomass Carbon (SMBC) (mg/kg)	Calculated from Soil Basal Respiration		
Potentially Mineralisable Nitrogen (PMN) (mg/kg)	Calculated from Soil Basal Respiration		
Potentially Releasable Phosphorus (PRP) (mg/kg)	Calculated from Soil Basal Respiration		
'Soil Your Undies'	*CottonInfo – Soil Your Undies*. Buried 1 pair of undies in surface 5cm layer and dug up approx. 60 days later	Low cost ($10/pair undies + time)	
Sub clover nodulation	*Ron Yates scoring system*[2]. Minimum of 15 plants analysed/site and averaged	Low cost (time)	
Soil organism count	*NQ Dry Tropics RASH Manual pg. 18*. Four samples/site and averaged	Low cost (time)	
Earthworm count	Used same 4 samples as 'soil organism count' (above) and averaged	Low cost (time	
Root depth	*Landcare RASH Manual pg. 22*. Four samples/site and averaged	Low cost (time)	
Groundcover percentage	*Landcare RASH manual pg. 11*. 100 points/site	Low cost (time)	
Physical Indicators			
Infiltration	*NQ Dry Tropics RASH Manual pg. 14*. Four samples/site and averaged	Low cost (time)	
Aggregate Stability (slaking and dispersion)	*NQ Dry Tropics RASH Manual pg. 16*. Four aggregates/site and averaged	Low cost (time)	

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