South West NRM
Building Healthy and Productive Ecosystems

Soil Constraints

To productivity in high rainfall pastures

(South West WA) - Technical Report

By Peter Clifton, May 2022

Contents

Acknowledgements

South West Catchments Council would like to thank Jeisane Accioly from Accioly Livestock Industries Services (ALIS) for engaging and liaising with the 24 farmers involved in the project, conducting soil and tissue sampling, scoring legume nodulation, preparing AMF samples, taking biomass cuts at one demonstration site, coordinating both events for this project and lifting the profile of the project by posting on social media and inviting a presentation at Western Beef Association Inc's 2019 Spring Field Day, for which she is the Executive Officer. Thanks also to Western Beef and their chair Ken Macleay for supporting the project.

Also, thanks to Graham Mussel at Graham Mussell Consulting for reviewing data and findings, assisting with bioassays and presenting at the final event.

Thanks to the 20 farmers involved and the four farmers that allowed and assisted us to conduct demonstrations on their farm: Mark Scott, Ken MacLeay, David and Linda Brumby and Paul Torissi.

Thanks to those who presented at events and/or provided advice or feedback on the project, including: Steve Carr, Neil Ballard, Sofie De Meyer, Daniel Kidd, Glenn McDonald, Megan Ryan, Jenni Clausen, Floyd Sullivan, Richard Bell, Martin Barbetti, Gaus Azam, Chris Gazey, Dan Parnell, Kirk Reynolds and Justin Mercy.

Introduction

The soil constraints project investigated the presence of soil constraints on high rainfall beef properties (> 600 mm annual rainfall). Failure to identify and manage a soil constraint can reduce nutrient and resource use efficiency. This has been the case in many farm trials looking for solutions without understanding the problem first.

Livestock producers in the South West typically only soil test to a depth of 10 cm. In this project, baseline surveys collected from 18 farmers showed that 78% had never tested below 10 centimetres, 61% had never tissue tested, 72% had never assessed legume nodulation, and 83% had never assessed compaction.

Increased monitoring may raise awareness of constraints, but broadscale adoption of a range of monitoring techniques is unlikely due to a lack of time and perceived benefit. However, if farmers are more aware of the most likely constraints, benefits of monitoring and effective monitoring techniques, they may prioritise resources.

The project aimed to characterise the extent of sub surface acidity, soil compaction, clover nodulation, macro and micronutrient deficiency, soil dispersion, and water repellency by surveying twenty farms. Two comparable "paired" sites on each farm, one underperforming and one performing better, were selected to attempt to isolate variables that may be reducing production.

The objective of the project was for beef farmers to have a better understanding of the extent and situation where constraints are likely to occur, be able to prioritise monitoring of these constraints, and be made aware of the most efficient strategy (e.g. timing, frequency) and monitoring techniques (e.g. tissue testing, bioassays, trials) to identify these constraints.

Four focus farms were also chosen to assess the value of multiple tissue testing across seasons, the seasonality of micronutrient availability, and to demonstrate some management options for constraints.

Methods

Site selection

***Figure 1**. Survey sites in red*

SWCC advertised for expressions of interest to beef cattle producers with a mean annual rainfall approximately greater than 600 mm. Twenty farms registered and had a variety of management intensities. Some practiced rotational or phased grazing over a limited number of paddocks, while some were set stocked. One grower was organic and two rotated paddocks with potatoes every 4–7 years. Most farms were fully commercial with approximately 40% supplementing income with off-farm work.

SWCC requested access to two 40 x 40 m sites per farm on twenty farms, ideally comparing a poor site with a good site on the same soil type, or two under-performing sites.

Sites were selected in March / April prior to significant plant growth by asking farmers for a representative and uniform location. Sites were at least 10 m from fences and tracks and avoiding gates and water troughs. Some sites were reduced to 30 x 30 m to maintain separation from fences, tracks and trees. One farm only had one site due to much of the small holding having rock below 10 centimetres, resulting in 39 sites.

Focus farms

Four farms were identified for small farm demonstrations. The primary purpose of these sites was to undertake tissue tests more than once through the season to capture variation. One 30 x 30 m site was selected on each focus farm. All sites were tested the same as the 20 farms and were included in regional averages, making 43 sites in total.

Soil testing

Three x 40 m transects were measured on an angle to fencelines, with the three transects forming a zigzag. The start and end point of each transect was GPS mapped. In each transect 15 cores were taken with a pogo-stick to 10 cm and bulked into one sample per transect. Two samples from the first and third transect were sent to CSBP Lab for analysis, with the middle sample held for follow-up if required (not used). The first sample was a comprehensive test with PBI and the second a standard test with PBI. All of the bulked sample was sent. As outlined, one of the twenty farms had one site, but another farm was sampled three times for soil (due to changes in soil type), which resulted in 40 sites tested.

The four focus farm sites were sampled in a similar manner (total 44 sites) but transects were only 30m long. All three transect samples were sent, two for standard tests and one for a comprehensive test.

Deeper samples were also taken at four corners of the site and one in the middle of each transect (7 cores) using a dig stick. The dig stick was marked at

10, 20 and 30 cm and samples taken for 10–20 cm and 20–30 cm, with the topsoil discarded. These were bulked and sent to CBSP lab for a comprehensive test with PBI.

Samples were collected between March 21 and April 12 2019 and sent for analysis in mid-April. Most soils were dry at sampling except for two farms that irrigate. Those samples were air dried.

Aluminium bioassay and additional soil tests

Subsurface soil tests in autumn of 2019 suggested that aluminium toxicity may be affecting pasture growth. However, the test used for aluminium (exchangeable aluminium) may not be suitable for WA soils because it extracts more aluminium and cations than plants can (Steve Carr, pers comm). Also, relatively high soil organic matter and the percolation of organic acids down the profile may detoxify any soluble aluminium.

To address these uncertainties, six sites on four farms with high exchangeable aluminium were revisited in January 2020. Soil was collected with an exhaust pipe from 0–10, 10–20 and 20–30 centimetre depths, resulting in 18 samples. Soil was mixed well and a 500g sub-sample was sent to CSBP lab for a standard soil test plus PBI with unwashed cations and aluminium in calcium chloride.

The remaining soil from each sample was split with one half limed with Boranup lime sand at a rate of 1 gram per kilogram of soil. The lime was mixed into the soil. The other half was unlimed. The limed and unlimed soil was put into four pots (5 x 5 x 12 cm) with two seeded with Moby barley and two with sub clover, resulting in the following treatments for each sample: limed barley, un-limed barley, limed sub clover, un-limed sub clover. These were watered for ten days and then roots extracted to compare root growth. Seed was not screened for size, but larger seeds were chosen.

Water repellence

During soil testing, a trowel was used to collect topsoil to a depth of approximately three centimetres. Crusted organic residue was removed from the topsoil before sampling, but some small fragments of residue remained in the sample. Three samples per site were collected. These were oven dried at 60 degrees and taken to DPIRD Albany where a Molarity of Ethanol droplet test was conducted. Two samples were tested, and the third only tested if there was a difference between the first two. Scores were then categorised using the table below. Water repellence was not collected at two irrigated farms, one which had three soil test sites, resulting in **39 sites**.

Molarity of ethanol	Description of severity
0	Not apparent
0.1-1.1	Low
1.1-2.3	Moderate
2.3-3.5	Severe
>3.5	Very severe

Figure 2. Classification used for soil water repellency, taken from Carter (2002).

Dispersion

Pea-sized aggregates were extracted from soil sample bags at each depth and dropped into de-ionised water in ice-cube trays. Dispersion was recorded at 2 hours and 24 hours.

Tissue testing

Using a handheld GPS and fence markings where possible, two plant tissue samples were collected along the same two transects that were soil tested. Sub Clover was targeted for sampling. Other plant material (e.g. ryegrass) was discarded and this was done quite methodically. If there wasn't enough clover in the sward, the two samples were bulked into a single sample.

Six sites did not have enough sub clover in the sward to make up a sample, so ryegrass was sampled instead, leaving 37 sites where sub clover was sampled (note the farm with three soil tests was only tissue tested at two sites). Sampling took place from 26 July until 11 September 2019. All samples were sent to CSBP Lab for a comprehensive tissue test (with molybdenum). Note that selenium and cobalt were not tested.

Clover root nodules

During tissue testing site visits, sub clover roots were also sampled from each site. A 30 x 30 cm square was dug with a spade at four locations at each site (two per transect) to 30 cm depth. The sod was dropped repeatedly to separate loose soil from roots, with the remainder reduced to a bag size (about 15 x 10 x 10 cm) and stored in a cooler box before returning to the Bunbury office. Each sample was carefully washed with a shower hose and larger plants were separated from the sod, made somewhat difficult by ryegrass root entanglement. Between two and four plants were separated per sod to make up a total of ten plants from the four sods per site. Nodules were scored following the chart below. An average score was taken across the ten plants. A total of **39 sites** were sampled, 37 sites with enough clover for tissue testing, and two that had some very small clover patches.

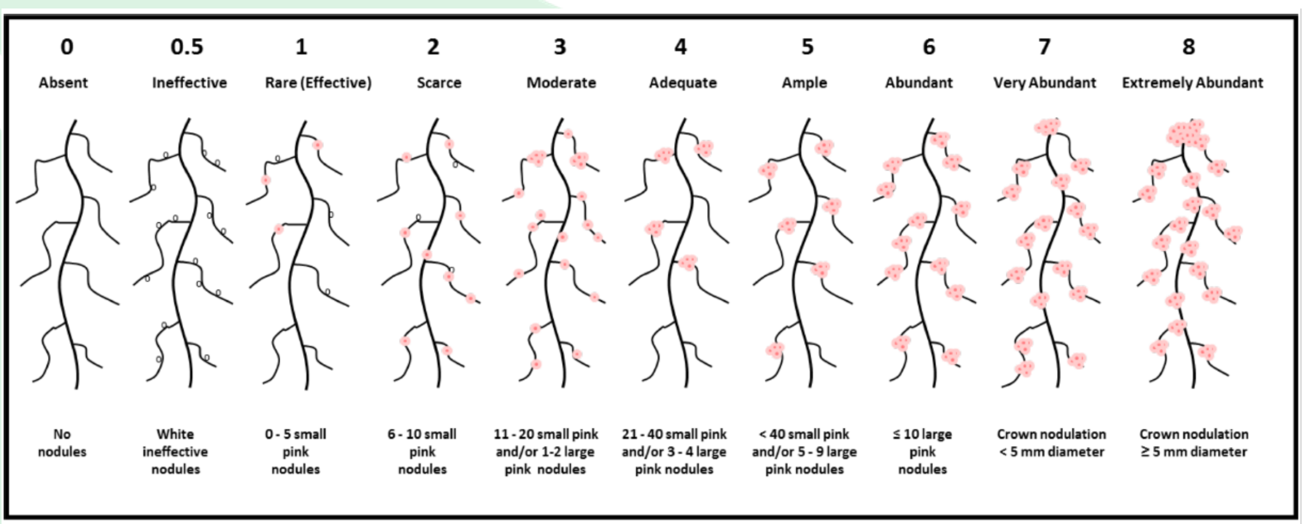

Figure 3. *Scheme used to assess legume nodulation, taken from Yates et al (2016).*

Soil Compaction

A CP200 penetrometer was hired from RIMIK and used to assess soil compaction at time of tissue and nodule sampling (25 July – 11 September 2019). The device recorded penetration resistance at 25 mm intervals as the tip pushed through the surface. The penetrometer was inserted at 1–2 cm per second as seen on the read-out screen, and would fail if the speed was too slow (so was repeated). The device stored data from up to 50 insertions. Each transect was sampled six times, resulting in 12 per site. Fencelines were also sampled if nearby (12 insertions per fence). Where only one fence was sampled (e.g. separating the two sites), the insertions per transect was increased to 8 (16 per site) and 16 along the fence. Data was downloaded and reviewed for outliers which were relatively common (e.g. a site sampled 12 times may only finish with 8 readings, especially at depth where compaction slowed the insertion speed and the penetrometer stopped recording). Failures were most common on electric fencelines which seemed to disrupt readings.

Data was analysed into median and standard error and also categorised into severe and moderate compaction using an interpretation from Penn State Extension (Figure 4, noting that 300 psi is equivalent to 2,068 Kpa).

Penetration data was not collected at one gravelly farm and one focus farm, while data from a second farm was lost, resulting in **38 sites tested**.

Percentage of measuring points having cone index > 300 psi in top 15 inches	Compaction rating	Subsoiling recommended
<30	Little-none	No
30-50	Slight	No
50-75	Moderate	Yes
>75	Severe	Yes
Adapted from: Lloyd Murdock, Tim Gray, Freddie Higgins, and Ken Wells, 1995. Soil Compaction in Kentucky. Cooperative Extension Service, University of Kentucky, AGR-161.		

Figure 4*. Interpretation of penetration resistance measurements. Taken from Penn State Extension*

Arbuscular Mycorrhizal Fungi (AMF)

Sub clover plants collected for nodule scoring were used to analyse AMF root colonisation. After nodules had been scored, fine roots were cut from 10 plants and placed in a vial with 70% ethanol solution. After all sites were sampled, vials were transported to the University of Western Australia's (UWA) School of Agriculture and Environment for analysis. The measurement method involved placing the roots randomly on a small grid and every time a section of root intersected the line, the presence or absence of AMF was recorded. The percent colonisation was calculated by dividing the “presence” figure by the sum of “presence” and “absence”. 37 sites were tested.

Site comparison

Data for each farm was compiled and differences between sites were identified. Where the difference was incidental (e.g. different phosphorus levels but both exceeding 95% production) it was ignored. Any deficiencies or constraints across both sites were also identified. The analysis was sent to Graham Mussell Consulting for review.

Results and discussion

Paired sites

Only six of the paired sites were in the same paddock or adjacent paddocks with seemingly the same undistinguishable soil type. Other farms had the same soil type but sites were some distance apart, while some were nearby with apparently the same soil but had significantly different phosphorus buffering index (PBI). The remainder had some differences in texture or colour.

Pairing sites in April was difficult due to the lack of plant growth; ideally pairing should be done during the growing season.

The variety of constraints meant correlations were difficult to find with any confidence.

Advice was provided to the twenty farms based on constraints that occurred at both sites, but the reason for lower production was difficult to identify. However, possible causes were noted.

Soil acidity

Soil pH_{Ca} is a good indicator of aluminium solubility and its likely concentration in soil solution. When soil pH_{Ca} drops below 4.8, aluminium becomes more soluble and potentially toxic to plants. This increases dramatically below 4.5 and can become toxic to tolerant species such as subclover and ryegrass if it drops below 4.3 (Fig.5).

Soil pH_{Ca} had a mean of 4.75 at a depth of 0–10 cm and was similar in clayey (4.7) and sandy soils (4.8). Thirty percent of 0–10 cm samples had a pH_{Ca} below 4.5. Samples taken from a depth of 10–20 cm revealed that 39 per cent of sites had a soil pH_{Ca} below 4.5, with a median value of 4.4 on sandy soils and 4.7 on clayey soils. In the 20–30 cm depth, 25 percent of samples were below 4.5 with median values of 4.6 in sandy soils and 4.9 in clayey soils.

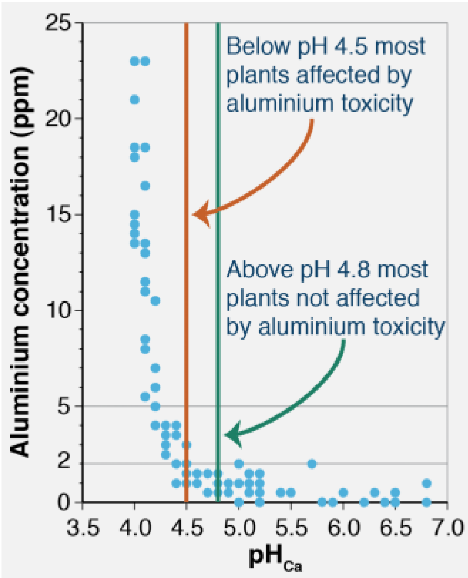

Figure 5. Relationship between pHCa and aluminium concentration in subsurface soils from a farm near Beacon (Source: DPIRD)

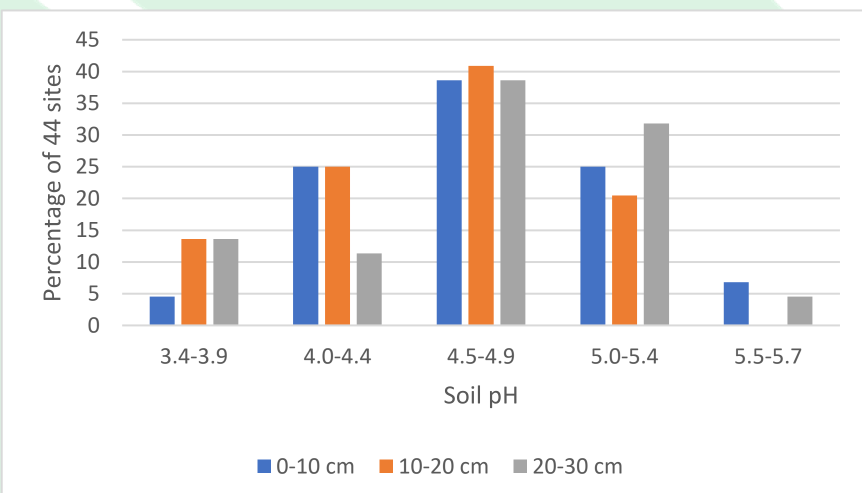

Figure 6. *Range of soil pH results at different depths*

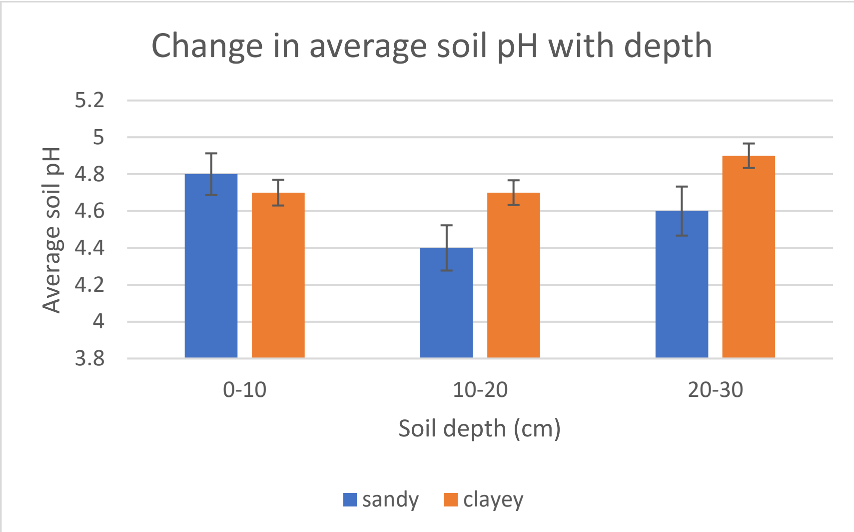

Figure 7. Change in average soil pH with depth and soil texture (with standard error bars).

These trends are concerning but not unexpected given that data held by the *Soil Quality* website shows 66 per cent of 169 permanent pasture sites in WA had a soil pH_{Ca} below 4.5 in the 10–20 cm zone.

This suggests that aluminium (Al) may often be soluble and potentially constraining high rainfall pastures.

The survey also found that nine of the 44 sites (20 per cent) had an exchangeable Al proportion greater than 30 per cent of cation exchange capacity in the 10–20 cm zone. An additional four sites exceeded 30 per cent in the 20–30 cm zone. These occurred on both sandy and clayey soil types. Preliminary comparisons in exchangeable Al between poorer and better sites suggest that Al toxicity may explain some difference in production on five of the 20 farms (25 per cent). Concerns with the veracity of the exchangeable aluminium test is covered in 4.3 below.

However, there was no indication that poorer sites tended to have lower soil pH, with levels often similar.

Low pH in the topsoil can reduce productivity in other ways, particularly where legumes such as sub clover are grown for nitrogen fixation. Nitrogen is fixed by rhizobia, which form nodules on legume roots. But rhizobia are sensitive to low pH, with subclover (Group C) strains preferring a range of 5.0 to 8.0. Another factor affecting nitrogen fixation is the availability of molybdenum, which decreases with decreasing soil pH. Nutrient availability for macro-nutrients such as phosphorus is also reduced by low soil pH. However, it should be noted that some micro-nutrients such as copper and zinc become more available at lower soil pH.

While an acidic subsurface can be ameliorated with alkaline products such as lime, alkalinity will only move through the soil profile where the topsoil pH is above 5.5. The SWCC survey recorded a median topsoil pH value of 4.7 on both sandy and clayey soils, and no site with a low subsurface pH had a topsoil result above 5.5. This suggests that improvement in subsoil pH is unlikely.

Soil pH also showed signs of stratification. On a focus farm with clayey soil, soil pH was measured at both 0–10 cm and 0–2.5 cm in three replicate plots. The mean soil pH value between plots in the top 10 cm was 5, while in the top 2.5 cm it was 6.1, indicating stratification of pH due to poor lime incorporation or movement down the profile. This suggests that part of the range between 2.5–10 cm was below a pH of 5 and suboptimal for legume nodulation, while the top few centimetres may be at an ideal pH.

Aluminium bioassay and additional soil tests

Following concerns that the exchangeable aluminium test is unreliable, some soils with high exchangeable aluminium were resampled and tested for both exchangeable aluminium and aluminium in $CaCl_2$. Results showed that some of these soils had enough aluminium to affect sensitive species such as barley, with one soil potentially toxic to clover roots. However, root growth recorded from pots didn't provide any definitive evidence of root pruning for either species. Exchangeable aluminium levels in 2020 differed significantly compared to April 2019 samples, suggesting there may have been contamination.

***Table 1**: Soils used in pot trials to observe effect of aluminium on barley and sub clover root pruning. *This sample was taken elsewhere in same paddock and was not sampled in April 2019. Yellow highlights suggest aluminium levels are sensitive to barley and red highlights levels are sensitive to clover. Results from a clayey soil in Kirup are not shown because Aluminium was below toxic levels.*

	Location	Busselton	Busselton	Vasse	Vasse
	Depth cm	10–20	20–30	10–20	20–30
	Texture	Sand	Sandy loam	Sand	Sand
Organic Carbon	%	2.0	0.9	0.9	0.5
pH Level ($CaCl_2$)		4	4	4.4	4.2
Aluminium ($CaCl_2$)	mg/kg	3.6	3.7	5.1	4.2
Ex Aluminium % Jan 2020		8.5	25.1	14.7	21.9
Ex Aluminium % April 2019		n/a*	60	39	55

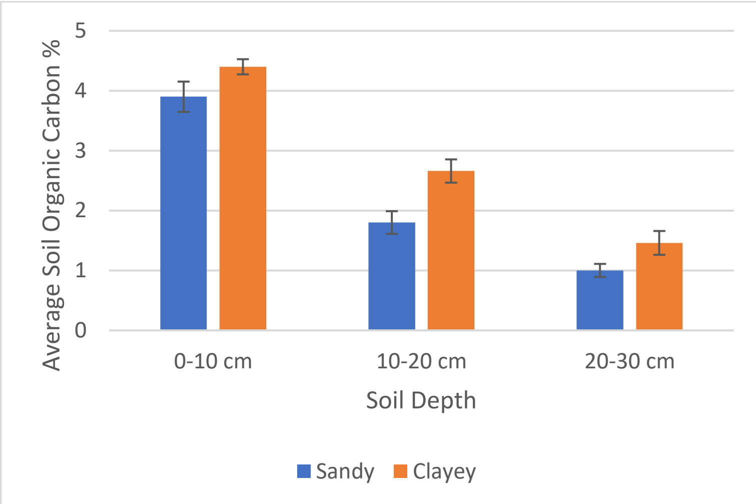

Figure 8. Change in soil organic carbon with depth and soil texture (with standard error bars).

Figure 9. Ten–day barley root growth in soil from the Busselton site at a depth of 20–30 cm.

Figure 10. Ten–day sub clover root growth in soil from the Vasse site at a depth of 10–20 cm.

Figure 11. Ten–day barley root growth in soil from the Vasse site at a depth of 20–30 cm

Figure 12. Ten–day sub clover root growth in soil from the Vasse site at a depth of 20–30 cm

Soil compaction

Almost half of the 39 sites sampled across 21 farms had a soil strength or compaction level that is likely to restrict root growth at a depth of 100 millimetres.

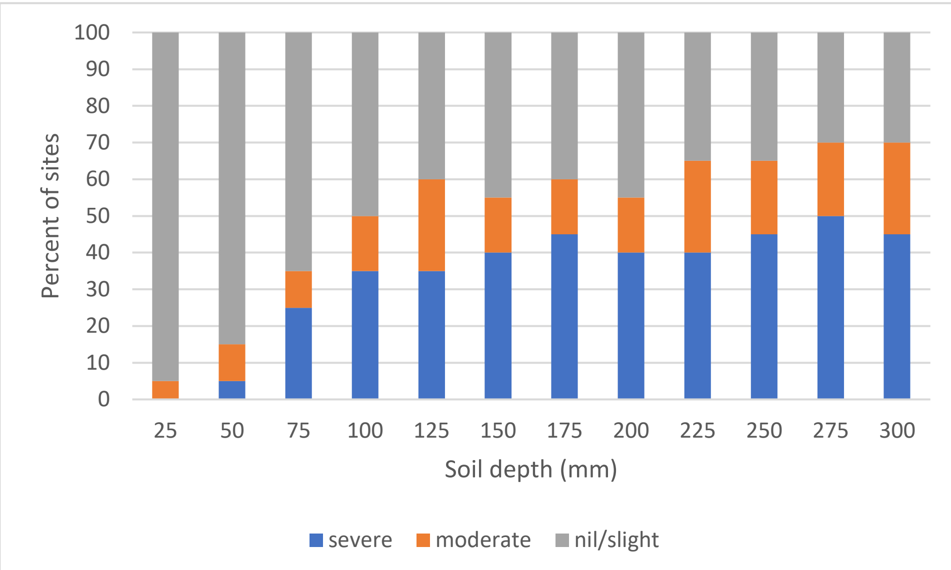

Figure 13. Soil compaction in sandy soils (20 sites on 11 farms).

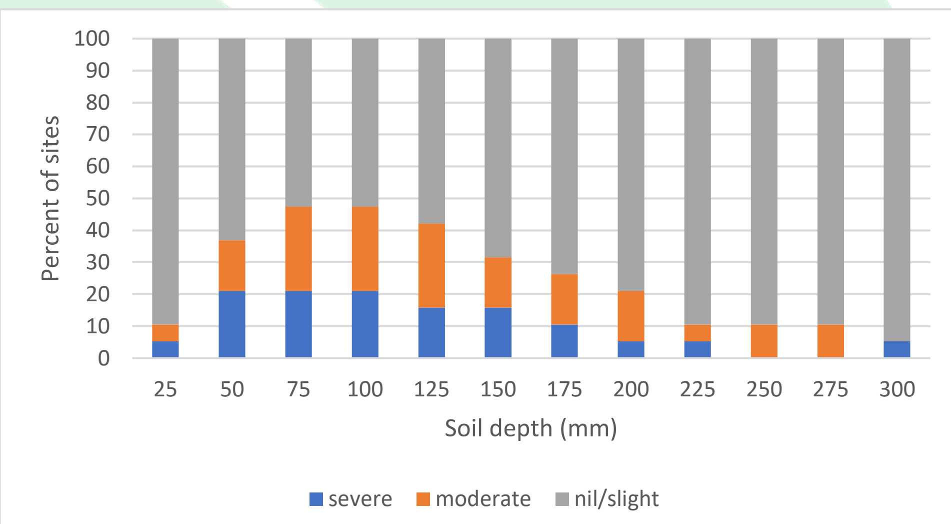

Figure 14. Soil compaction in clayey soils (19 sites on 10 farms).

Results suggest that sandy soils are most prone to compaction, which tends to increase with depth at a decreasing rate. Fifty percent of sites showed some form of compaction at 100 mm and 55% at 200 mm with the majority of these severely compacted (35 and 40% respectively).

Compaction in clayey soils was less evident and tended to be shallower, peaking at 75 to 100 mm before declining with depth. The highest incidence of severe compaction occurred from 50 to 100 mm and was seen at 21% of sites. Compaction at 50 mm was much higher in clayey soils (37%) compared to sandy soils (15%).

However, penetrometers do have some limitations such as not capturing pores formed by earthworms, dung beetles and root channelling. Anecdotal observations suggest that earthworms were more common in clayey soils and often absent in sandy soils. Also, accurate reading is difficult in gravelly soils. Very gravelly soils could not be sampled, while small percentages of gravel (e.g. 5%) may overestimate compaction.

Results are also influenced by soil moisture. Resistance increases as soils dry out, so surveys were conducted between late July and early September 2019 when soil moisture was relatively high to capture the best-case-scenario for roots. However, dry periods during surveying meant that in some cases there had not been any rain for several days prior to sampling.

Readings were recorded along fencelines where possible as a comparison to assess the effect that dry soil and gravel may have had on results. Only one of 20 fences sampled had severe compaction, which occurred between 200 and 300 mm on a sandy soil. Five other fences had moderate compaction, but only one of these was above a depth of 200 mm. This suggests the impact of dry soil and gravel was minimal. The one farm with significant fenceline compaction was excluded from results.

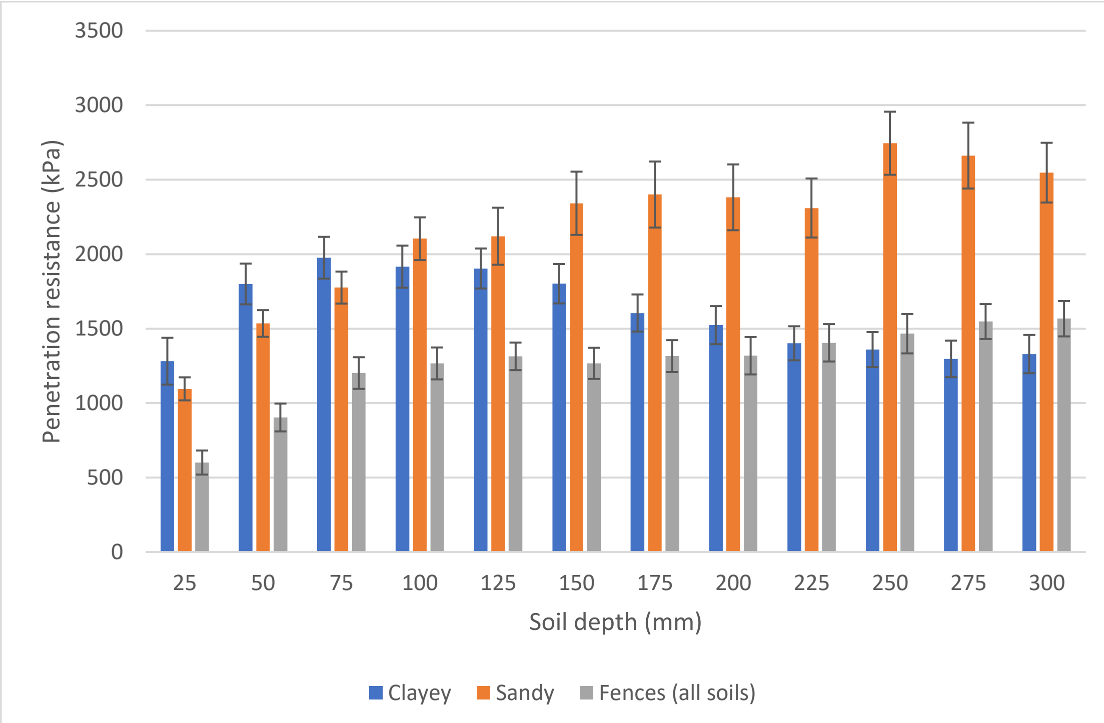

Figure 15. Median soil strength (compaction) for sandy and clayey soils along fencelines (with standard error bars).

Surveys also compared poor performing sites with better performing sites on the same farm and with the same soil type. Sites were identified by the farmer based on previous year's growth. There was little evidence of any correlation between compaction and poor performance. While this suggests that the effect of compaction on pasture growth is moderate, most sites had other constraints that may confound or mask the effect of compaction, making it difficult to draw conclusions.

Water repellence

As expected, sandy soils tended to be severely water repellent, while clayey soils tended to have low water repellency. Water repellency was typically the same or similar at paired sites on each farm.

Table 2. Water repellency ratings from 40 sites on 22 farms, with most common rating for each soil type highlighted.

Rating\soil type	Sand	Sandy loam	Loam	Clay loam	Clay	Total
Very severe	0	2	0	0	0	2
Severe	4	9	1	0	0	14
Moderate	0	2	1	2	2	7
Low	0	2	0	6	6	14
Not apparent	0	0	0	1	2	3
Total	4	15	2	9	10	40

Soil dispersion

There was little evidence of soil dispersion, although slaking was common.

Nodule health

The average nodule score from 39 sites was 2.64 which is considered scarce (score = 2) to moderate (score = 3). The most common categorisation was moderate and the highest was adequate (score = 4). No sites were categorised as ample or above (scores 5 to 8).

Sampling time extended from July 25 to October 14 2019. There was a trend of increasing nodule health as the season progressed, which is to be expected. Of the seven sites scored in September/October, five were adequate. Adjusting for this time of assessment, it is estimated that the average may have been approximately 3.25 at all farms in spring, suggesting that the best description for sub clover nodule health in the survey is moderate, described as 11 to 20 small nodules and/or 1 to 2 large nodules per plant.

The validity of the assessment was checked by sending 43 images with scores to consultant Neil Ballard. The average score of samples sent was 3.4. Dr

Ballard scored the same samples at an average of 2.4, suggesting our scores were conservative, even accounting for an increase in nodule health later in the season.

One issue with the survey was the density of plants. In cases where subclover was dominant and dense, plant roots tended to be spindly with few small nodules, whereas fewer clover plants tended to have bigger root systems with larger nodules. The scoring system does not account for this so should be considered crude and, in this situation, potentially conservative. Another issue is the presence of ryegrass in terms of competition for resources and difficulty in separating roots. Some roots may have been broken or nodules removed during disentanglement. Therefore, it may have been better to measure the number of nodules per centimetre of root length as suggested in FAO Visual Soil Assessment Guides.

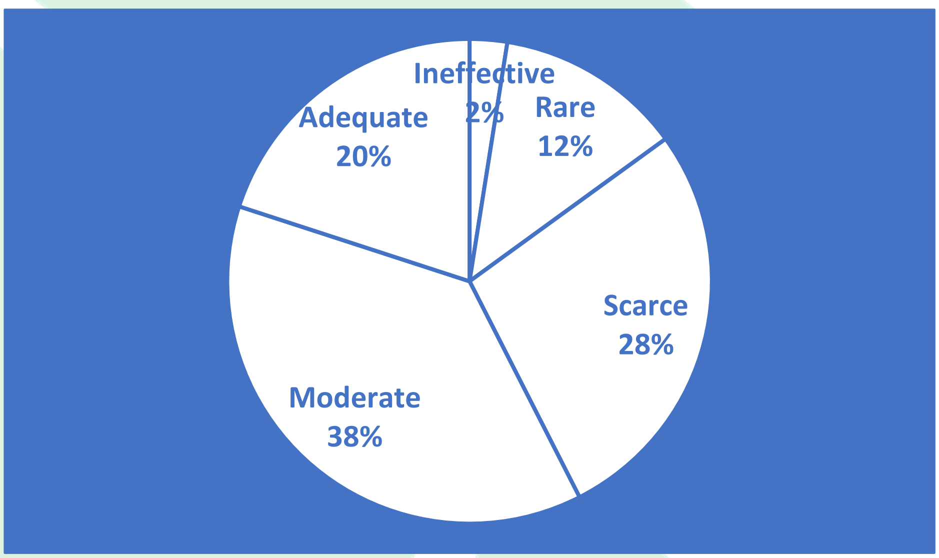

Figure 16. Nodule health categorisation

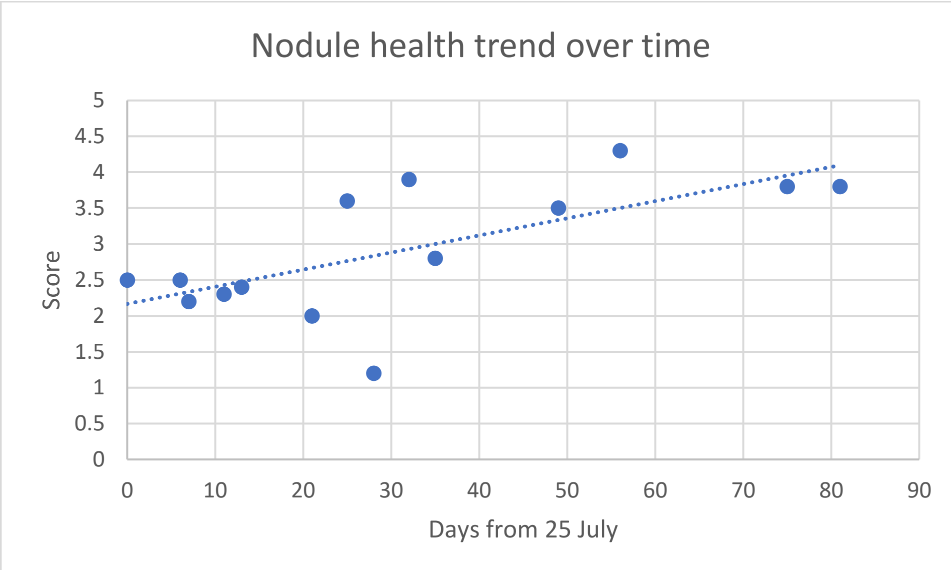

Figure 17. *Nodule health results over time*

Arbuscular Mycorrhizal Fungi

The mean percentage of roots colonised by arbuscular mycorrhizal fungi (AMF) was 71% and median score was 76%. Tables 4 and 5 below show some trend in colonisation with soil type, tending to be lower in sandier soils with lower Phosphorus Buffering Index (PBI). There was no indication that AMF colonisation was lower in poorer paddocks compared to better paddocks on the same property. It was actually more common to have lower rates in better paddocks, although actual differences appear to be inconsequential.

Table 3. Phosphorus Buffering Index (PBI) Categories

PBI Category	Rating	Colour code
<5	Extremely low	
5–10	Very low	
10–15	Low	
15–35	Moderately low	
35–70	Medium	
70–140	Moderately high	
140–280	High	
280–840	Very High	

Table 4: Farms with higher than median AMF colonisation

Location	Soil type	Relative Production	AMF colonisation +	AMF colonisation –	% colonisation	Intensity	Comments	PBI Category**
Ferguson*	Loam	n/a	86	2	98	VH	Replicates	High
	Clay		88	4	96	VH		
			85	5	94	H		
Kirup 1		better	88	10	90	VH		Very High
	Clay	lower	65	3	96	VH		High
Pemberton	Loam – clay loam	n/a	62	5	93	VH		Very High
	Loam + 5% gravel		88	11	89	VH		
Cowaramup	Loam – clay	n/a	90	11	89	VH		Very High
			84	14	86	VH		
Wilga	Gravelly Sandy loam	better	50	9	85	VH	Gravelly	High
		lower	49	5	91	VH	Replicates. Gravelly	
			40	6	87	VH		
Anniebrook	Sandy loam	better	53	23	70	VH		Very High
	Clay		93	10	90	VH		High
	Clay loam	lower	83	11	88	VH		Very High

Location	Soil type	Relative Production	AMF colonisation		% colonisation	Intensity	Comments	PBI Category**
			+	–				
	Clay		80	18	82	VH		
Upper Capel 1	Clay	n/a	58	25	70	L		High
			69	16	81	VH	High colonisation but low intensity	
			81	7	92	H		
Upper Capel 2	Loam – clay loam	better	53	29	65	H	Irrigated	High
	Sandy loam	lower	74	14	84	VH	replicate	Medium
			69	16	81	H	replicate	High
Capel	Sandy loam	better	74	8	90	L	Antas clover	Moderately high
			58	17	77	L		
			84	27	76	M		
	Sand-Sandy loam	poor	90	18	83	VH		Moderately low
Kirup 2	Clay	better	79	20	80	M		Very high
	Sandy loam – clay loam	lower	74	21	78	H		

** Focus farm where samples were taken from three adjacent 10x30m plots. Two soil types separated by a hyphen (–) indicate where legume roots were taken from two transects 30m apart with different soil types.*

*** PBI was measured from 15 bulked cores along each transect, whereas AMF was only sampled from plants at 2 points along each transect. Focus farms showed significant variation in PBI between three transects within a 30x30m plot (29–37; 193–236; 333–427).*

***Table 5**. Farms with median or below median levels of colonisation*

Location	Soil type	Relative Production	AMF colonisation		% colonisation	Intensity	Comments	PBI Category
			+	–				
Uduc	Clay loam – clay	good	13	63	17	L	Healthy, thick uncut roots	High
	Clay	poor	59	19	76	L	Thin roots	
			55	14	80	M	Peas	
Middlesex	loam	better	80	23	78	VH	Rotated with potatoes	High
	Sandy loam – loam	lower	69	27	72	VH		Very high
Kirup 3	clay	better	51	20	72	L	High colonisation but low intensity	Very high
			66	27	71	M		
	Clay loam–clay	lower	60	20	75	L		
Yallingup	Sand–sandy loam	better	46	31	60	M		Very low
		lower	48	15	76	H		Extreme. low
Collins		n/a	54	37	59	M		

Location	Soil type	Relative Production	AMF colonisation +	AMF colonisation –	% colonisation	Intensity	Comments	PBI Category
	Sandy loam		64	26	71	VH	Rotated with potatoes	Moderately high
Yoongarillup	Sand	better	70	45	61	H	Lots of vesicles. Replicates	Moderately low
			54	37	59	L		
	Sand-sandy loam	lower	78	40	66	VH		
			66	17	80	VH		
Manjimup	Sandy loam	better	48	41	54	M		Moderately low
		lower	45	34	57	M		
Nannup*	Clay	n/a	43	40	52	M		Very high
	Loam	n/a	48	32	60	M		
	Clay	n/a	71	64	53	H		
Scott River 1	Sandy loam	better	79	41	66	L	Brown grey sand	High
		lower	23	53	30	L	Grey sand	Extreme. low
Vasse*	Sandy loam	n/a	37	46	45	L		Moderately low
			28	70	29	H		
			27	52	34	L		
Scott River 2		better	16	82	16	VL	Roots look healthy.	Extreme. low – low

Location	Soil type	Relative Production	AMF colonisation		% colonisation	Intensity	Comments	PBI Category
			+	–				
	Sandy loam	lower	20	82	20	VL	Highest tissue P (>0.43mg/kg)	Extreme. low

** Focus farm where samples were taken from three adjacent 10x30m plots. Two soil types separated by a hyphen (–) indicate where legume roots were taken from two transects 30m apart with different soil types.*

*** PBI was measured from 15 bulked cores along each transect, whereas AMF was only sampled from plants at 2 points along each transect. Focus farms showed significant variation in PBI between three transects within a 30x30m plot (29–37; 193–236; 333–427).*

Sub clover root disease

After sending root samples and photos of root systems to UWA to help assess nodule and AMF, it was noted by researcher Daniel Kidd that many of the photos suggested severe root disease. World expert Professor Martin Barbetti from UWA was contacted and sent the same 43 images. Professor Barbetti provided a quick assessment of each photo over the phone.

Approximately two thirds of the photos were described as having severe root rot, evidenced by dark and stubby roots and sparse root systems.

According to Professor Barbetti, root rot is a complex of several diseases, the main ones being *Aphanomyces*, *Pythium*, *Rhizoctonia* and *Phytophthora*. Pre-emergent and post-emergent damping off can result in the loss of 90 percent of seedlings.

While plant mortality is an extreme outcome, root rot can also reduce nodulation, plant growth and nutritional value of sub clover.

Disease on the tap root is considered very severe, often resulting in complete collapse of the root system below the lesion. Disease on lateral roots can also be severe, but these roots can be replaced when conditions become warmer in spring.

Figure 18. *An example of a severely diseased root system with dark, short lateral roots.*

Figure 19. The lesion on this tap root is likely to collapse the root below.

As growth improves in spring, less affected roots can grow away from the shallow organic layer where disease is concentrated.

The importance of root growth means that good grazing management and nutrition that promotes root growth can help the plant withstand disease. The use of organic amendments that increases microbial activity could also increase competition for some fungal pathogens and supress their effect.

In contrast, when growing conditions for plants are poor in winter, root rot is often most severe.

Monitoring sub clover density and health during winter can help identify the presence of disease. Plants with severely damaged root systems often show signs of stress such as stunted growth with yellowing or red-purple foliage, and stressed plants can occur amongst healthy-looking plants. These signs can be symptomatic of other stresses such as phosphorus deficiency, so digging up and washing plant roots will provide a more reliable indication of disease, commonly seen as brown or stubby laterals or damaged tap roots.

Monitoring for root rot is complicated by the presence of multiple diseases with an unpredictable nature. Disease tends to vary from year to year and from site to site, sometimes occurring as patches in a paddock and sometimes in one paddock and not another.

Nutrient deficiency

Tissue test raw data was analysed by Graham Mussell Consulting using September calibrations on tests mostly done in August. Table 7 below shows the frequency of sites with potential deficiencies (where at least two sites record a deficiency).

Test results from CSBP came with NuLogic analysis that also categorised nutrient status. Marginal results are not expected to result in lost productivity.

Molybdenum is not classified by CSBP into low, marginal, sufficient or high. This data was classified by the author based on discussions with agronomists and researchers that resulted in an assumption that levels below 0.2 mg/kg were likely to be deficient or low.

High levels of molybdenum can also induce copper deficiency. It is considered that levels above 1.5 mg/kg create a risk, especially where sulfur levels are high.

Table 6. Frequency of sites with potential deficiencies identified by Graham Mussell Consulting in tissue tests.

	Possible	Likely	definitely
Nitrogen	2	2	0
Phosphorus	7	1	0
Potassium	3	0	1
Sulfur	2	3	0
Copper	2	1	0
Zinc	1	1	0
Molybdenum	12	11	0
Nitrogen/Sulfur ratio	0	5	0
Grass Tetany (low magnesium)	0	0	4

Table 7. Frequency of sites with deficiencies in certain nutrients identified by CSBP NuLogic analysis of 37 subclover sites (ryegrass tested on 6 sites typically had no deficiencies apart from boron at 4 sites). One of the 37 sub clover sites had high sodium.

	Low	Marginal	Sufficient	High
Total Nitrogen	0	5	32	0
Phosphorus	8	18	11	0
Potassium	4	19	13	1
Sulphur	0	9	25	3
Copper	1	6	19	11
Zinc	0	2	26	9
Manganese	0	7	27	3
Calcium	0	1	6	30
Iron	0	1	24	12

Table 8. Sub clover Molybdenum results from CSBP lab analysis (mg/kg).

	Below 0.1	0.1–0.2	0.2–0.5	0.5–1.5	Above 1.5
Site Count	8	6	9	7	7
Percent	22	16	24	19	19

Tissue tests suggest that molybdenum is the most commonly deficient element. This may be due to a lack of molybdenum maintenance required every 5–10 years, and soil acidification which reduces the availability of molybdenum. Six farms had at least one site with molybdenum in sub clover below 0.1 and an additional 5 had at least one site below, totalling about 50% of farms. It is also notable that several farms had very high levels of molybdenum that may increase the risk of copper deficiency.

In terms of macronutrients, deficiencies do not appear to be common. Phosphorus may be the exception, with CSBP identifying 8 of 37 sites to be low, while Graham Mussell Consulting identified 7 sites that are possibly deficient.

Doing tissue tests in winter to enable time for a spring application may not be an effective strategy. This is because many deficiencies don't show until well into September when full growth expressed. Therefore, it may be a better strategy to sample in September and treat the following year.

Multiple tissue tests from focus farms show the variation in tissue test values and categorisation through the growing season (below).

Tissue test results for macronutrients can be compared to soil tests. The figure below shows the percent of relative production likely to be achieved based on soil phosphorus and PBI (assuming no other constraints). Most notable from this figure is 40% have too much phosphorus. Some may be deficient if they are targeting high production targets compared to current levels. However, many producers run low stocking rates and don't require high levels of pasture production.

For sulfur and potassium, soil tests indicate minimal deficiency, although many sandy sites appear marginal for potassium. The opposite could be said for clayey soils, where potassium appears to be in oversupply in the top 10 cm.

Also, of interest from soil tests is the availability of macronutrients down the profile. Phosphorus is potentially deficient at 10–30 cm depth on half the sites. Sulfur shows a similar trend, while potassium appears significantly deficient in sandy soils from 10–30cm.

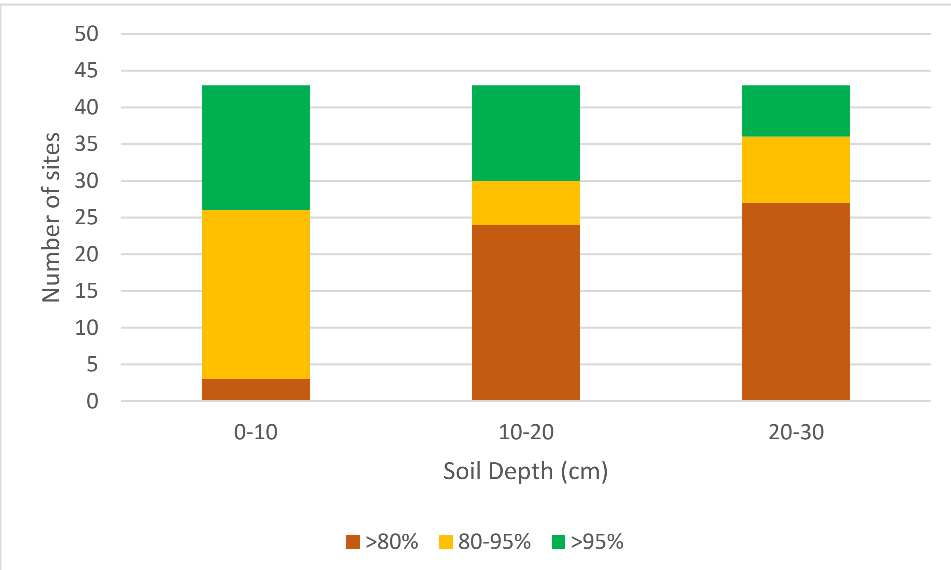

Figure 20. *Soil phosphorus fertility with depth.*

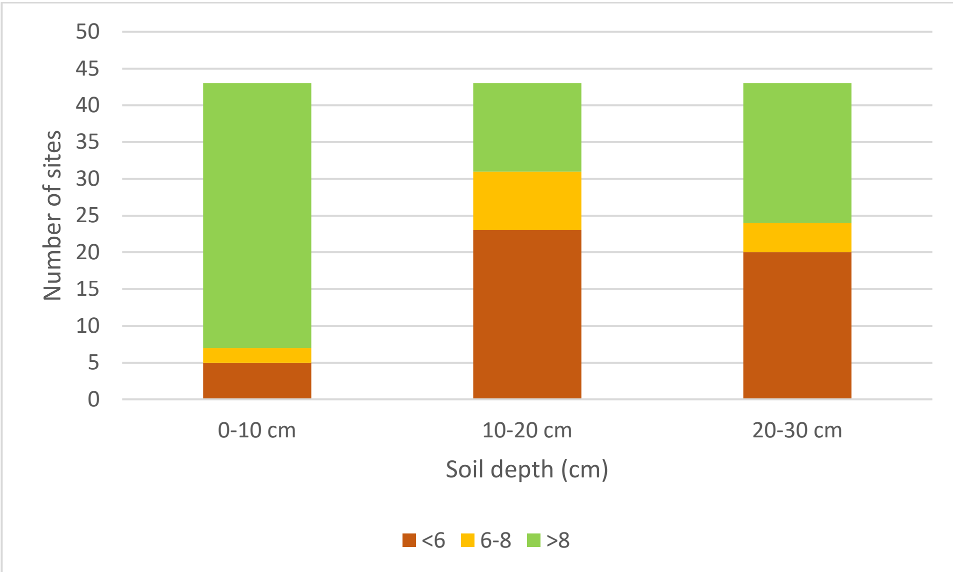

Figure 21. Soil sulfur fertility (mg/kg) with depth.

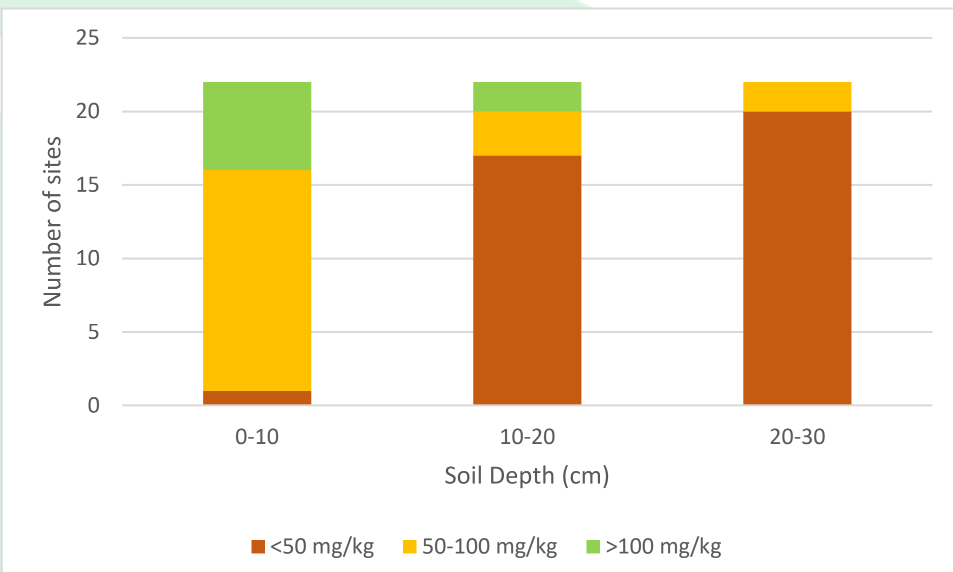

Figure 22. Sandy soil potassium fertility with depth.

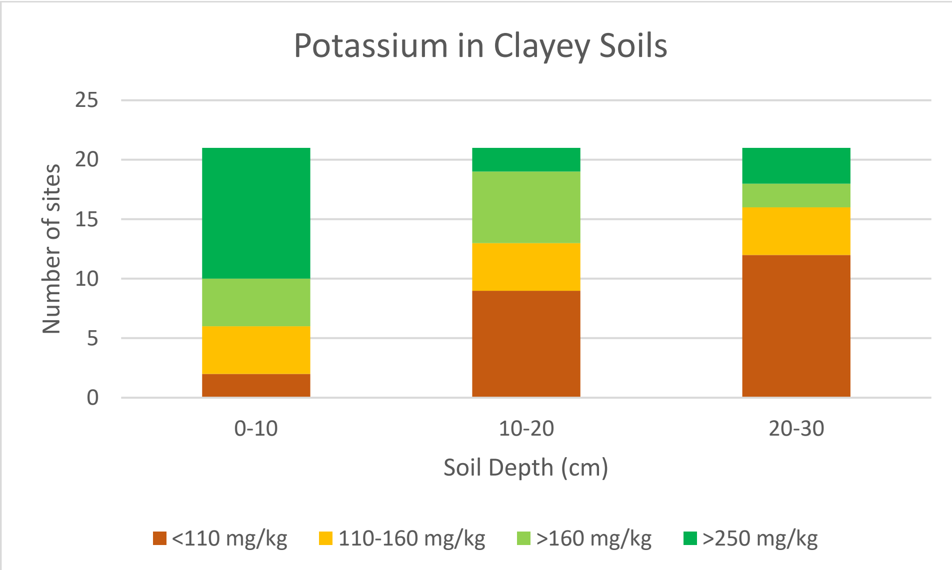

Figure 23. Clayey soil potassium fertility with depth.

Table 9. Change in tissue test nutrients at focus farms over time with CSBP NuLogic categorisation

Location	Date 2019	Replicate	Crop Type	Tot N	P	K	B	S	Na	Ca	Mg	Cu	Zn	Mn	Fe	Cl	NO_3N	Mo
Ferguson	24/07	Rep 1	Clover	4.28	0.26	2.53	18.98	0.28	0.28	0.85	0.22	11.86	24	40.13	315.31	0.54	< 40.00	244.08
Ferguson	14/10	Rep 1	Clover	4.15	0.19	2.07	18.14	0.22	0.49	1.79	0.28	10.57	15.09	57.31	97.01	0.71	< 40.00	36.77
Ferguson	24/07	Rep 2	Clover	4.33	0.25	2.31	20.11	0.27	0.42	0.79	0.21	13.2	28.74	47.87	534.32	0.5	< 40.00	296.77
Ferguson	29/08	Rep 2	Clover	4.36	0.23	2.91	21.02	0.25	0.26	1.09	0.22	13.03	17.1	53.01	199.01	0.58	< 40.00	73.2
Ferguson	14/10	Rep 2	Clover	4.62	0.18	1.94	16.79	0.26	0.33	1.9	0.26	12.51	21.75	82.62	88.67	0.38	< 40.00	11.84
Ferguson	24/07	Rep 3	Clover	4.28	0.25	2.57	18.62	0.31	0.29	0.85	0.21	11.95	31.84	47.51	349.74	0.74	51.51	330.91
Ferguson	14/10	Rep 3	Clover	3.76	0.2	1.93	21.05	0.27	0.81	2.02	0.33	13.05	16.67	66.31	76.02	0.79	< 40.00	18.1
Vasse	26/08	Rep 1	Clover	4	0.28	1.25	23.88	0.23	0.93	1.15	0.22	6.3	43.79	50.56	176	0.51	< 40.00	754.29

Location	Date 2019	Replicate	Crop Type	Tot N	P	K	B	S	Na	Ca	Mg	Cu	Zn	Mn	Fe	Cl	NO_3N	Mo
Vasse	08/10	Rep 1	Clover	2.92	0.18	0.54	24.81	0.23	1.42	1.86	0.26	7.54	46.08	62.14	61.55	1.1	< 40.00	891.99
Vasse	26/08	Rep 2	Clover	3.97	0.3	1.17	25.15	0.23	0.73	1.28	0.25	7.35	40.65	49.88	129.3	0.45	< 40.00	943.48
Vasse	08/10	Rep 2	Clover	3.24	0.17	0.63	23.34	0.26	1.34	1.8	0.26	7.65	50.78	77.27	69	1.01	< 40.00	791.34
Nannup	12/08	Nil N	Rye	4.03	0.46	4.18	4.08	0.42	0.16	0.34	0.18	9.35	21.29	132.8	120.51	1.53	550.65	650.07
Nannup	19/09	Nil N	Rye	3.38	0.51	4.41	4.14	0.41	0.17	0.48	0.19	8.9	18.34	150.3	92.66	1.63	237.46	702.63
Nannup	12/08	Intense N	Rye	5.92	0.34	3.65	4.69	0.47	0.36	0.33	0.18	10.24	23.32	97.88	123.94	1.13	2520.3	532.49
Nannup	19/09	Intense N	Rye	3.85	0.46	3.86	5.11	0.46	0.41	0.59	0.2	9.93	23.4	144.8	118.98	0.99	122.49	583.94
Stratham	31/07	Time 1	Rye	5.15	0.51	3.99	4.29	0.38	0.06	0.59	0.17	5.86	23.31	38.68	323.77	0.7	910.71	3282.07

Location	Date 2019	Replicate	Crop Type	Tot N	P	K	B	S	Na	Ca	Mg	Cu	Zn	Mn	Fe	Cl	NO_3N	Mo
Stratham	31/07	Time 1	Rye	5.28	0.48	4.11	4.89	0.37	0.07	0.66	0.19	8.19	31.34	51.95	625.7	0.63	1338.5	2473.67
Stratham	04/09	Time 2	Rye	2.07	0.38	2.48	5.11	0.21	0.11	0.56	0.16	3.5	11.6	50.4	389.55	0.57	< 40.00	2867.83
Stratham	04/09	Time 2	Rye	1.77	0.3	1.98	4.95	0.18	0.11	0.53	0.13	3.78	15.27	70.04	826.11	0.57	< 40.00	2222.11

Key learnings

The project suggests that soils supporting beef pastures in the South West's higher rainfall zone have multiple constraints. Specifically, it found the following trends across 24 farms:

1. Fungal disease was severe on two thirds of farms. This is likely to reduce the productivity of sub clover, the density of lateral roots and root nodules, nitrogen fixation and animal nutrition. Any reduction in root biomass is likely to limit the plant's ability to find nutrients, making the system inefficient.

2. Soil pH was low, averaging 4.7 in the top 10cm. In the subsurface, pH in sandy soils tended to decline further in the 10–20 cm layer but get no worse and in some cases improve in the 20–30cm layer, averaging 4.4 and 4.6 between 10–20 and 20–30cm respectively. This suggests sampling to 20cm may be sufficient to assess subsoil pH. In clayey soils, pH remained steady, averaging 4.7 and 4.9 at lower depths.

3. There was some indication that aluminium is at toxic levels. However, bioassays suggest that root growth may not be affected. This could be due to high levels of soil organic matter detoxifying the aluminium, unreliability of tests, contamination of samples or a combination of these.

4. Soil pH was significantly stratified at one site, having a soil pH of 6.1 in the top 2.5 centimetres and 4.9 in the top ten centimetres. So, despite results, pH may be ideal in the top few centimetres, but more marginal below that depth than results suggest.

5. Low topsoil levels suggest that lime will not reach and therefore will not neutralise soil acidity below a 5–10 cm depth without incorporation.

6. Molybdenum levels were considered low on 10 of 21 farms. Molybdenum is required to ensure nodules develop and fix nitrogen properly. This result is likely to be influenced by soil acidity where molybdenum is less available. However, it may also reflect a lack of

molybdenum application in fertiliser, something that may need to occur every five to ten years, which is more often than other micronutrients such as copper and zinc. Given that soil tests are less reliable in detecting micronutrient deficiencies compared to tissue tests, and the rate of molybdenum drawdown, this trend supports the use of comprehensive (i.e. with molybdenum included) tissue testing every five years, noting that standard tests don't normally include molybdenum.

7. Only 20% of farms had adequate nodulation. The more common situation was to have moderate nodulation (37.5%) or scarce nodulation (27.5%). The remaining 15% was either rare or ineffective. This result is likely to be influenced by the issues outlined above. Given its relationship with multiple factors, and the fact that rhizobia tend to be more sensitive to acidity compared to the host plant, nodule health may be a useful indicator of soil health.

8. Soil compaction was higher in paddocks compared to fencelines. Compaction in clayey soils peaked between 5 and 12.5 cm depth, with 21 percent of sites showing severe compaction. Compaction in clayey soils declined below 12.5 cm. In sandy soils, 25% of sites were severely compacted at 7.5 cm and this gradually increased with depth to 50% at 27.5 cm. Compaction may increase disease risk as roots are typically slower to grow in compacted soils and therefore less able to grow away from the top 5–10 cm where disease is most common.

9. As expected, sandy soils tended to be severely water repellent, while clayey soils tended to have low water repellency.

10. Arbuscular Mycorrhizal Fungi (AMF) was assessed at all sites as a potential indicator of soil health. Despite high rates of root disease observed, AMF levels appeared healthy with a median of 76% of root mass colonised across all sites. There was no trend between colonisation and perceived pasture productivity. Results did suggest a trend between AMF and soil type, either in terms of clay content or phosphorus buffering index.

11. The survey trialled several methods to assess constraints, each with its own benefits. These include:

    a. Tissue test – collect samples in spring when growth rates have peaked so any deficiencies will show. Sample before flowering. Sample the species most sensitive to nutrient deficiencies in the desired sward. This is typically the legume. For molybdenum analysis, a comprehensive test is typically required. This test can quickly isolate deficiencies if they exist, although an agronomist may be required to interpret "marginal" results which may or may not require action. Marginal results don't mean a level is low or growth is affected.

    b. Pairing diagnostic sites compares a poor site with a better site on the same soil to diagnose the constraint at the poorer site. It is important to select sites during the growing season to isolate differences in production. However, tests don't always isolate reasons for different production levels, suggesting that more inherent factors such as soil texture or phosphorus buffering index may play a part.

    c. Bioassays can be used to test whether aluminium toxicity is affecting root growth deeper in the profile. It is done by taking subsurface soil, sowing seeds and watering for ten days. Pots need to be well watered to minimise negative effect of dry soil. Any comparison in soils requires seeds to be the same size. Seedlings are washed out from soil after ten days and root length compared.

    d. Checking plant roots and nodules – Without checking roots, the constraint of soil-borne disease on sub clover would not have been detected, so this method may be vital to ensure all constraints are known. Washing needs to be done carefully and ryegrass roots can make sub clover root and nodule extraction difficult. Assessing root health is typically based on colour (white-good, brown-poor), the number and length of roots and any swelling or lesions present. Tap root damage is considered most severe. Scoring nodules is a subjective measure and the colour of nodules needs to be assessed carefully.

e. Soil test at other depths – Typically use an exhaust pipe or dig stick to access depth. This is time consuming and perhaps not great value for money given relationships with 0–10 cm and uncertainty attached to aluminium tests. A 10–20cm sample is likely to be sufficient with the 20–30 cm sample often not providing more information.

f. Digital soil penetrometer – An efficient means of characterising soil compaction, but not suitable for gravelly soils. A penetrometer is relatively expensive. Alternatively, a shovel can provide a fair indication of compaction. Regardless of equipment, soil should be sampled when soil moisture is at field capacity, not waterlogged or dry, so that the best conditions for plant growth are represented. Compaction under these conditions means it will only be worse as soils dry. Comparison between paddocks and over time is difficult due to changes in soil type, moisture and gravel, so comparing with the closest fenceline is preferable.

g. Water repellency – a laboratory test was conducted for close comparison, but this will be difficult for farmers. However, tipping deionised water onto undisturbed soil and counting seconds until it soaks in is an easy method.

Conclusion

Research suggests that an optimally performing legume can provide about 25 kilograms of nitrogen for every tonne of legume dry matter grown per hectare, released slowly over three years. This project has highlighted the poor productivity of sub clover in terms of nodulation and nitrogen fixation. This is likely to be related to several soil constraints, including fungal pathogens, low molybdenum and low soil pH. Pathogens may also affect sub clover productivity in terms of establishment, survival and growth, possibly accentuated by compacted soil that limits root growth and resilience to disease.

Management of these issues could take the form of sowing sub clover varieties that are more disease resistant, maintaining soil pH at 5 or above, maintaining molybdenum levels, inoculating clover with the most effective strains potentially every five years, and possibly cultivating every 4–10 years to 10 centimetres, which would treat compaction and incorporate lime to avoid stratification of pH. The decision to cultivate should consider the level of compaction, disease, need for lime incorporation and potential to combine with seeding operations, compared against potential erosion, loss of soil fertility and potential increase in nematodes.

Assessment of these factors requires comprehensive tissue testing of sub clover near the start of spring every 5 years to monitor molybdenum (and other) levels or molybdenum application every 5–10 years, soil tests to monitor soil pH to at least 20 centimetres, possibly in 5 centimetre increments to capture stratification, assessment of compaction levels (e.g. with a spade) when soils are wet but not flooded, and the careful extraction of sub clover roots to assess nodulation and root disease. Assessment of sub clover root health may be a valuable indicator of overall soil health.

This project was delivered by South West Catchments Council, through funding from the Australian Government's National Landcare Program, in partnership with Western Beef Association Inc.

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