Insights into the health of soils in the Glenelg Hopkins catchment

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Contents

Abstract

A soil benchmarking program that involved sampling and testing 100 sites distributed across the Glenelg Hopkins catchment was established by Southern Farming Systems (SFS) with assistance from the Centre for eResearch and Digital Innovation (CeRDI) and the Glenelg Hopkins Catchment Management Authority (CMA). Initial soil testing has identified the main issue affecting the catchment to be soil acidity, with 62% of the sites below pH ($CaCl_2$) 5.0 at 0-10 cm. In the subsoil, 52% and 26% of the sites at 10-20 cm and 20-30 cm respectively were below pH($CaCl_2$) 4.8. Another issue identified was high phosphorus levels with 32% of soils rated as having excess phosphorus, that is above 25 mg/kg (Olsen) test. However, carbon levels within the catchment were generally optimal with 61% exceeding 3% organic carbon which would be attributed to soil type, rainfall, and fertile systems involving pastures which build carbon.

1.0 Introduction

The Glenelg Hopkins Catchment Management Authority (CMA) is responsible for the management of natural resources across a land area of some 26,910 km^2 of south west Victoria. The GHCMA strives to achieve a healthy and sustainable balance between the natural environment and the community's use of land and water resources. Soil, as a natural resource, is the basis of agricultural production. With around 81% of the Glenelg Hopkins CMA land area dedicated to farming, the Glenelg Hopkins CMA places priority on working with the community to adopt farm practices that improve and protect our soil resources, and sustainably achieve production and profit targets.

The Glenelg Hopkins Sustainable Agriculture project, Soils4Farms, is a partnership between the Glenelg Hopkins CMA, Southern Farming Systems (SFS), Agriculture Victoria, WestVic Dairy and Landcare. Funded through the Australian Government's National Landcare Program (NLP), Soils4Farms aims to increase awareness and adoption of land resource management practices that protect the condition of soil, vegetation and biodiversity on farmland; prioritising reducing risks of soil acidification. In this way, Soils4Farms contributes to the achievement of the Australian Government's priority 5-year outcomes for Sustainable Agriculture.

While the Glenelg Hopkins CMA has been successful in supporting regional farmers to more sustainable farming systems, inadequate data sources have meant knowledge of changes to soil condition across the region over time are not known. With the establishment of 100 soil monitoring sites, and soil testing at each site, this project provides a benchmark of soil condition across the Glenelg Hopkins CMA region. Testing of sites in future years will enable changes in soil condition to be identified. In addition, the soil data gathered through this project will inform and guide initiatives to improve soil condition by the Glenelg Hopkins CMA and project partners. In 2019/20, the soil data, and other soils information, will be made publicly accessible enabling individual farmers to utilise this knowledge to make informed land management decisions.

This report outlines methods used to select and sample the 100 monitoring sites, and the laboratory methods used to undertake testing. Statistics arising from preliminary analysis of the soils data are presented and discussed.

2.0 Method

A campaign to recruit farmer volunteers to host a soil monitoring site on their farm resulted in 196 expressions of interest, and nominations by SFS, the Glenelg Hopkins CMA, Agriculture Victoria and other service providing staff. A selection process was undertaken involving representatives of the Glenelg Hopkins CMA, SFS and CeRDI. The 100 sites selected offered an even geographical spread with major soil types, land uses, and climate zones represented. SFS coordinated and undertook the sampling of 100 sites across the Glenelg Hopkins CMA catchment region.

Paddock history forms were sent to each of the growers. See 7.1 Appendix 1 for a blank paddock history form. The purpose of the paddock history form was to assist in helping to understand paddock results.

Ten cores, to a depth of 30 cm, were randomly taken within a 25 m^2 grid area using a hydraulic soil corer with a diameter of 42 mm. Each core sample was separated into 0-10 cm, 10-20 cm and 20-30 cm samples. Samples were individually bagged and labelled. The grid and sample point locations were marked as Global Positional System (GPS) points and were recorded using Trimble FarmWorks Software. For the purpose of soil description, two deep cores to a depth of 80 cm were taken from within this 25 m^2 area. The deep cores were taken to CeRDI, where they will be characterised into the Australian Soils Classification System.

Sampling was undertaken from mid-February to early April 2019. It was the aim to have sampling completed before the autumn break for ease of trafficability across paddocks, and prior to fertiliser application. Sampling was undertaken prior to fertiliser application on most sites, with the exception of some dairy farms which apply fertiliser every six weeks.

For calculation of the bulk density, composite samples (0-10 cm, 10-20 cm and 20-30 cm) of the 10 cores were air dried in the oven at 40°C until they reached a constant weight. They were put in the oven for three days, weighed, put back in the oven for an additional 48 hours and if they had lost less than 3% of their weight in moisture, they were considered air dry. Reduced representative composite samples were created through thoroughly mixing, and in necessary cases crushing (by hand or using a hammer or crowbar).

The samples were posted to CSBP Soil and Plant Analysis Laboratory in Perth, Western Australia. The 0-10 cm samples were tested for Phosphorus (Olsen), Phosphorus (Colwell), Potassium (Colwell), Sulfur, Electrical Conductivity, pH ($CaCl_2$), pH (H_2O), Total Carbon (LECO), Colour, Gravel Percentage, Texture, Ammonium Nitrogen, Nitrate Nitrogen, Exchangeable Aluminium, Exchangeable Calcium, Exchangeable Magnesium, Exchangeable Potassium, and Exchangeable Sodium. 10-20 cm and 20-30 cm samples were tested for pH ($CaCl_2$), pH (H_2O), Electrical Conductivity and Total Carbon (LECO).

The total carbon measured in the project can contain inorganic carbon contaminates, usually carbonates or bicarbonates such as lime. Samples that had soil pH ($CaCl_2$) above 6.0 were suspected to contain inorganic carbon and so these samples (23, 10, 68, 79 and 87) were fizz tested with acid to determine the presence of carbonates and where carbonates were found they were removed with sulphurous acid and then re-analysed and their carbon levels amended. As a result of this process three samples were amended (site 23 and site 87). For the remaining samples, their carbon levels are reflective of organic carbon and are referred to in this report as organic carbon.

Table 1: Laboratory tests and methods used for analysis of soil at different depths.

Test	0-10 cm	10-20 cm	20-30 cm	Laboratory method used
Phosphorus (Olsen)	✓			Rayment and Lyons Method 9C2
Phosphorus (Colwell)	✓			Rayment and Lyons Method 9B
Potassium (Colwell)	✓			Rayment and Lyons Method 18A1
Sulphur (KCl 40)	✓			Rayment and Lyons Method 10D1
Electrical Conductivity	✓	✓	✓	Rayment and Lyons Method 3A1
pH ($CaCl_2$)	✓	✓	✓	Rayment and Lyons Method 4B41
pH (H_2O)	✓	✓	✓	Rayment and Lyons Method 4A1
Total Carbon	✓	✓	✓	Rayment and Lyons Method 6B2
Ammonium Nitrogen	✓			Rayment and Lyons Method 7C2b
Nitrate Nitrogen	✓			Rayment and Lyons Method 7C2b
Exchangeable Aluminium	✓			Rayment and Lyons Method 15G1
Exchangeable Cations*	✓			Rayment and Lyons Method 5A4
Texture	✓			CSBP laboratory method
Gravel content	✓			CSBP laboratory method

*Calcium, Magnesium, Sodium and Potassium

Bulk density was calculated using the total air-dry weight of the 10 cores taken at each depth (0-10 cm, 10-20 cm and 20-30 cm). However, due to some soils having high content of buckshot, accurate separation of layers at all sites was not always possible and will render some samples at 10-20 cm and 20-30 cm inaccurate.

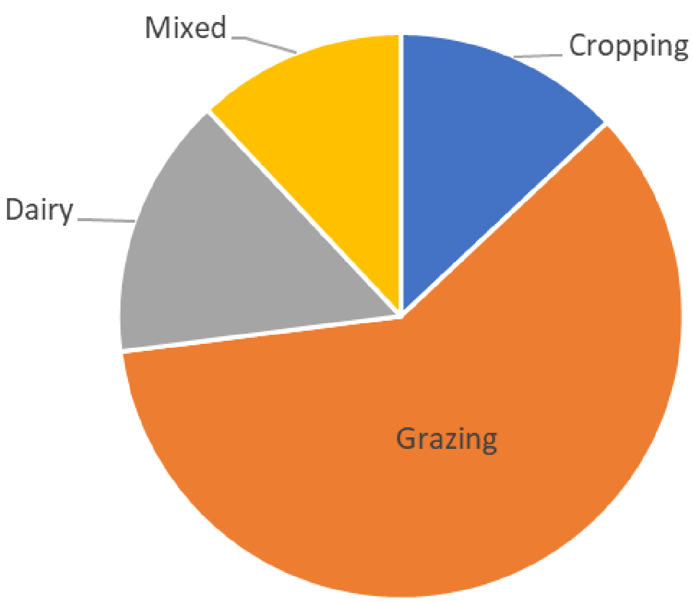

Figure 1: Enterprise breakdown of sites surveyed in the Glenelg Hopkins catchment.

Enterprises (on an individual paddock basis) were put into four categories based on paddock history forms: cropping, grazing (sheep and beef), dairy and mixed (cropping and beef/sheep). Cropping has been defined as paddocks that have been continuously cropped for at least the last 4 years as shown in the paddock histories.

Figure 1 shows that most (60%) of the sites were sheep or beef grazing enterprises, followed by 15% dairy, 13% continuous cropping, and 12% mixed cropping and livestock.

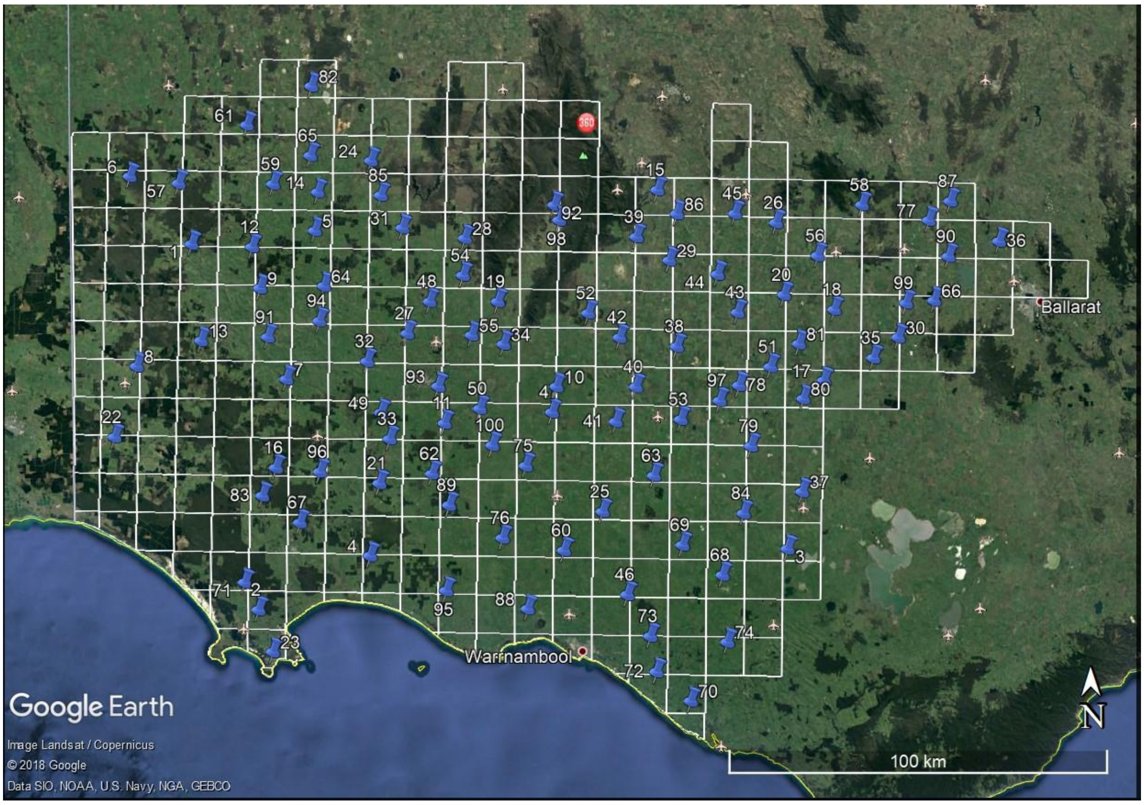

Figure 2. Locations and identification numbers of sites sampled across the catchment.

Assessment of intact cores into likely Australian soil classification categories will be completed by CeRDI.

3.0 Results and discussion

3.1 Catchment statistics

(a) Soil depth 0-10 cm

Table 2: Statistics for different soil tests for the Glenelg Hopkins catchment 0-10 cm.

Test	Units	Mean	Standard deviation	Maximum	Minimum
Phosphorus (Olsen)	mg/kg	21.3	15.2	99.5	2.6
Phosphorus (Cowell)	mg/kg	59.5	50.1	349	4
Potassium (Colwell)	mg/kg	231.1	172.0	1363	30
Sulphur	mg/kg	16.4	17.4	138.2	3.2
pH ($CaCl_2$)		4.9	0.5	7.3	3.9
pH (H_2O)		5.7	0.4	8	4.9
Electrical Conductivity	dS/m	0.1	0.1	1.4	0.02
Organic Carbon (Leco)	%	3.7	1.8	10.7	0.5
Ammonium Nitrogen	mg/kg	13.3	9.3	61	3
Nitrate Nitrogen	mg/kg	26.2	17.4	91	2
Cation Exchange Capacity	meq/100g	10.1	8.9	58.2	1.5
Calcium:Magnesium ratio		4.6	3.5	20.3	0.5
Sodium % of cations (ESP)	%	4.1	3.1	26.8	0.7
Aluminium % of cations	%	4.9	6.5	33.7	0.1

(b) Soil Depth 10-20 cm

Table 3: Statistics for different soil tests for the Glenelg Hopkins catchment 10-20 cm.

Test	Units	Mean	Standard deviation	Maximum	Minimum
Conductivity	**dS/m**	0.06	0.08	0.66	0.01
pH ($CaCl_2$)		4.82	0.49	7.30	3.80
pH (H_2O)		5.82	0.47	7.90	4.70
Organic Carbon (Leco)	**%**	1.99	1.05	5.56	0.47

(c) Soil Depth 20-30 cm

Table 4: Statistics for different soil tests for the Glenelg Hopkins catchment 20-30 cm.

Test	Units	Mean	Standard deviation	Maximum	Minimum
Conductivity	**dS/m**	0.06	0.07	0.53	0.01
pH ($CaCl_2$)		5.06	0.55	7.60	3.80
pH (H_2O)		6.10	0.54	8.20	4.93
Organic Carbon (Leco)	**%**	1.32	0.81	4.54	0.15

3.3 Soil organic carbon

(a) 0-10 cm

Soil organic matter, which is where carbon in stored, is essential for maintenance of the physical, chemical and biological properties of soil. Optimum soil organic carbon levels in soil are greater than 2% for cropping and greater than 3% for pastures (Botta, 2016).

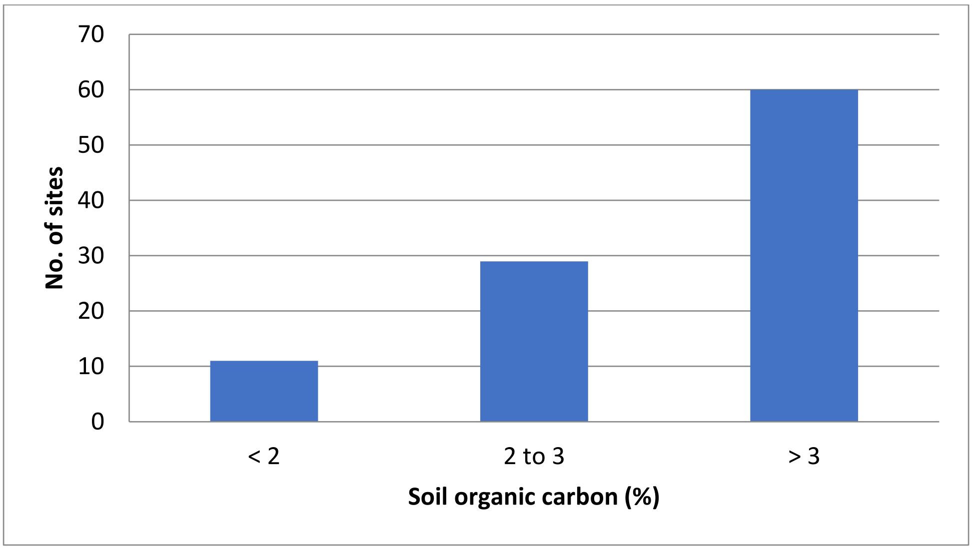

Figure 1: Frequency of soil organic carbon (%) at 0-10 cm from 100 sites.

Figure 3 shows a histogram of soil organic carbon (%). Less than 2% is considered too low, 2-3% is moderate, and greater than 3.1% is considered optimum. Ranges are from Greenwood et al. (2008).

As shown in Figure 3 above, 11 of the sites had a total carbon reading of less than 2%. Table 5 below shows that six of the sites with low soil organic carbon were near the Grampians (sites 27, 38, 82, 86, 92 and 98) where there is light textured soil and lower rainfall compared with other parts of the

Glenelg Hopkins catchment. Four of the 13 sites that had been continuously cropped over the last four years also had soil organic carbon of less than 2%.

The number of sites with greater than 3% organic carbon was 60. Higher rainfall results in more soil organic matter and therefore an increase in soil carbon. This is due to increased rainfall promoting greater plant growth, which results in increased organic matter in soil. Soils containing a higher proportion of clay retain and build more organic matter than lighter textured soils. This is because soils containing more clay retain more moisture, and the clay binds to organic matter, helping to protect it from being broken down by microbes and other organisms (Hoyle, 2013).

Table 5: Sites with less than 2% carbon, and their location, enterprise and texture.

Site ID	Enterprise	Carbon (%)	Texture
1	Grazing	1.51	Sand/Loam
7	Grazing	1.74	Sand/Loam
8	Grazing	1.41	Loam
27	Grazing	1.97	Loam
38	Cropping	1.64	Loam/clay
51	Cropping	1.95	Clay
61	Grazing	1.30	Loam
82	Cropping	0.95	Sand/Loam
86	Cropping	1.28	Clay
92	Grazing	0.52	Clay
98	Grazing	1.51	Sand/Loam

Thirty-nine of the sites had a soil organic carbon reading of less than 3%, with 12 sites being light textured. Figure 4 shows the range in soil carbon results.

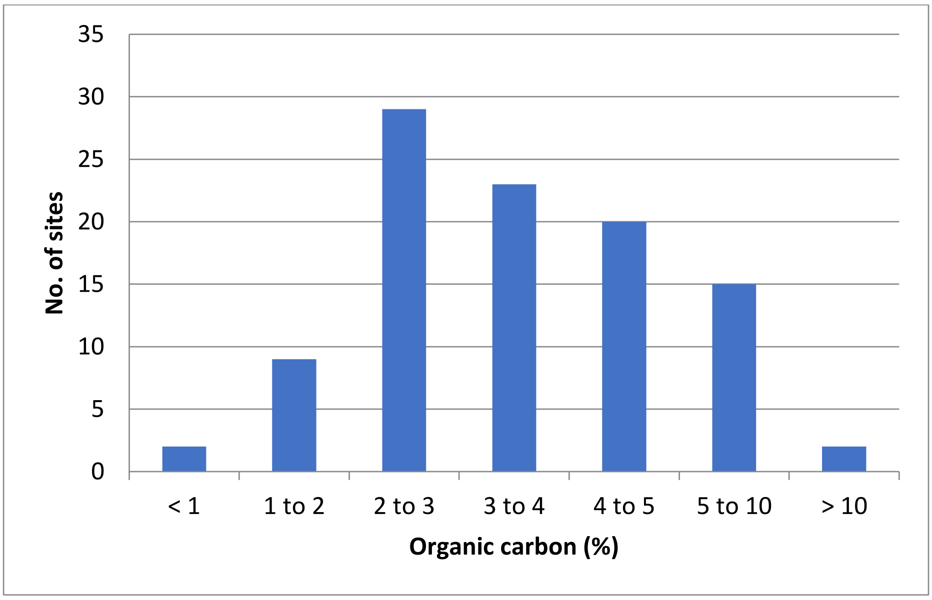

Figure 4: Frequency of soil organic carbon (%) at 0-10 cm from 100 sites.

Note: In all histograms, a category labelled (for example) 1 to 2 includes sites with data from 1.1 to 2.0.

(b) 10-20 cm and 20-30 cm

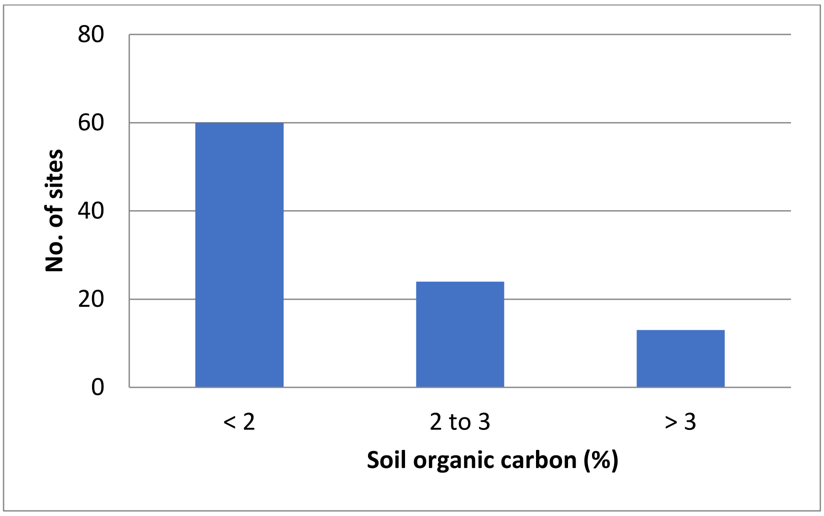

Figure 2: Frequency of soil organic carbon (%) at 10-20 cm from 100 sites.

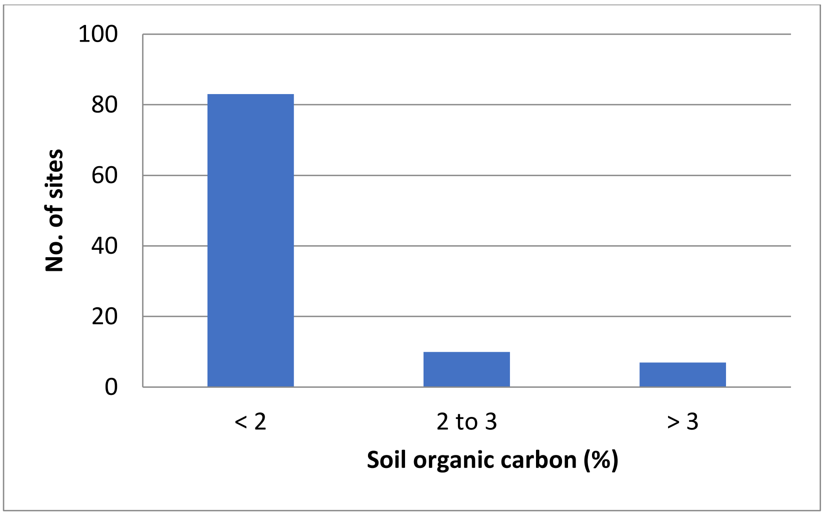

Figure 3: Frequency of soil organic carbon (%) at 20-30 cm from 100 sites.

As shown in Figures 4 and 5, most of the carbon is in the top 10 cm of soil and falls away at deeper depths. This is typical of soils in eastern Australia (Hobley and Wilson, 2016). Figure 4 shows that most sites (60) has less than 2% soil organic carbon at 10-20 cm. Figure 5 shows that seven of the sites had soil organic carbon exceeding 3% at a depth of 20-30 cm, and that most sites (83) has less than 2% soil organic carbon. These sites were all grazing, mixed or dairy enterprises; no continuously cropped sites had soil organic carbon exceeding 3% at this depth.

Table 6: Sites with soil organic carbon exceeding 3% at different depths and their texture.

Site ID	Soil organic carbon % 0-10 cm	Soil organic carbon % 10-20 cm	Soil organic carbon % 20-30 cm	Texture (0-10 cm)
9	4.79	3.32	3.42	Clay
11	5.93	4.08	2.85	Clay
16	6.5	3.99	3.99	Clay
46	7.38	4.48	2.95	Clay
47	3.58	3.39	1.77	Clay
67	3.35	3.33	3.33	Clay
68	10.19	4.75	3.55	Clay
75	3.6	3.6	2.97	Clay
79	6.35	3.55	2.25	Clay
84	3.54	3.1	2.23	Clay
91	7.39	5.56	3.74	Clay
96	6.01	4.93	4.93	Sand
100	10.66	5.35	4.54	Clay

As shown in Table 6 above, only one site with soil organic carbon exceeding 3% from 0-20 cm did not have clay textured topsoil. Site 96, with a sandy texture topsoil, was on a high rainfall dairy pasture with a soil pH($CaCl_2$) of 3.9, 3.8 and 3.9 for each soil depth. Clay soils hold more organic matter and therefore more soil carbon than other soil textures.

3.4 Phosphorus (Olsen)

Phosphorus is used in plants for energy storage and transfer, early shoot and root growth (making it crucial for seedlings and young plants), and legume nodulation processes. Twelve to 15 mg/kg is aiming for 85-90% of production, while 15 to 18 mg/kg is aiming for 90-95% of production (Victorian Government Department of Primary Industries, 2007).

Phosphorus (Olsen) levels ranged between 2.6 mg/kg and 99.5 mg/kg, with a mean of 21.25 mg/kg. Of the 100 sites, 39 of them were lower than the critical target for phosphorus (Olsen) to grow pastures at 95 to 100% of potential production, as there was less than 15 mg/kg of phosphorus present (Botta, 2016). Thirteen sites had phosphorus levels of less than 8 mg/kg, which can result in issues with retaining sown perennial plant species (McCaskill, 2016). Thirty-two of the sites had excess phosphorus in the soil, with more than 25 mg/kg (Victorian Government DEPI, 2007; Dairy Australia, 2019). Of the 15 sites tested that were dairy farms, 11 had phosphorus levels of greater than 25 mg/kg. Excess phosphorus in soil is not a risk for plant growth, however applying excess fertiliser is a waste of financial resources. Excess phosphorus can also wash into waterways, with the potential of causing algal blooms (Summers and Weaver, 2018).

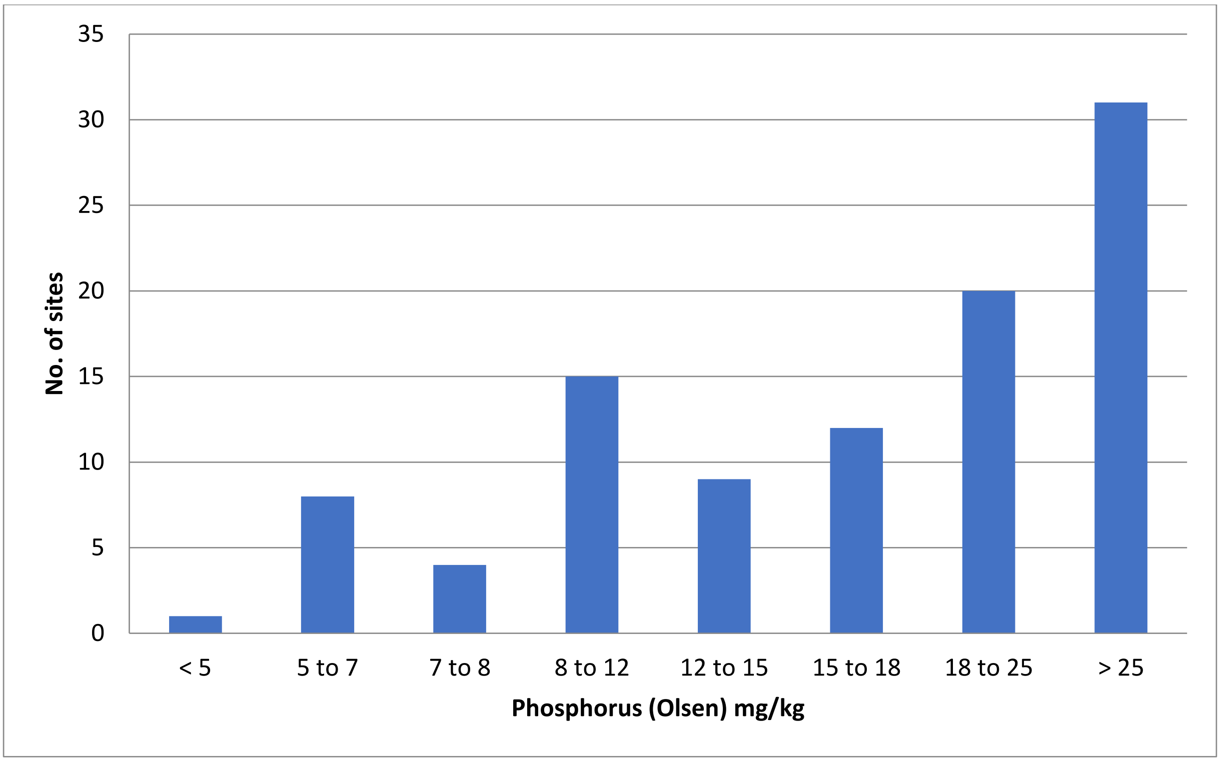

Figure 4: The frequency of the levels of soil phosphorus (Olsen) mg/kg at 0-10 cm from 100 sites.

3.5 Potassium (Colwell)

Potassium is a macronutrient for plants, and is important for regulating nutrient uptake, flowering, seed set, and plant resistance to environmental stresses and disease (Botta, 2016). Potassium deficiency results in inefficient water use, as it helps with the opening and closing of the plant's stomata (pores) and if deficient, the plant loses water, making potassium important for drought tolerance (Scanlan, 2015).

Potassium (Colwell) levels ranged between 30 mg/kg and 568 mg/kg, with a mean of 220 mg/kg. Soil in a grazing enterprise can be considered potassium deficient when levels are below 100 mg/kg in most soil types. In a cropping enterprise, crops may not show a response to additional potassium unless levels are below 50 mg/kg (Grains Research and Development Corporation, 2014). However, it is thought that responses may vary with soil texture as they do in grazing enterprises and that more even production occurs at levels above 80 mg/kg. Of the 100 sites, 20 had a potassium deficiency. Six of the potassium deficient sites had been continuously cropped or cut for hay in the past four years.

There was one reading outside this range (site 91, 1363mg/kg), however this was not included in the calculations. The site in question has had no potassium fertiliser applied in the last four years, however it is downhill from a road that dairy cows are walked back and forth along twice a day. Therefore, the most likely cause of high potassium in the soil is the run-off from the road of their urine, which is high in potassium.

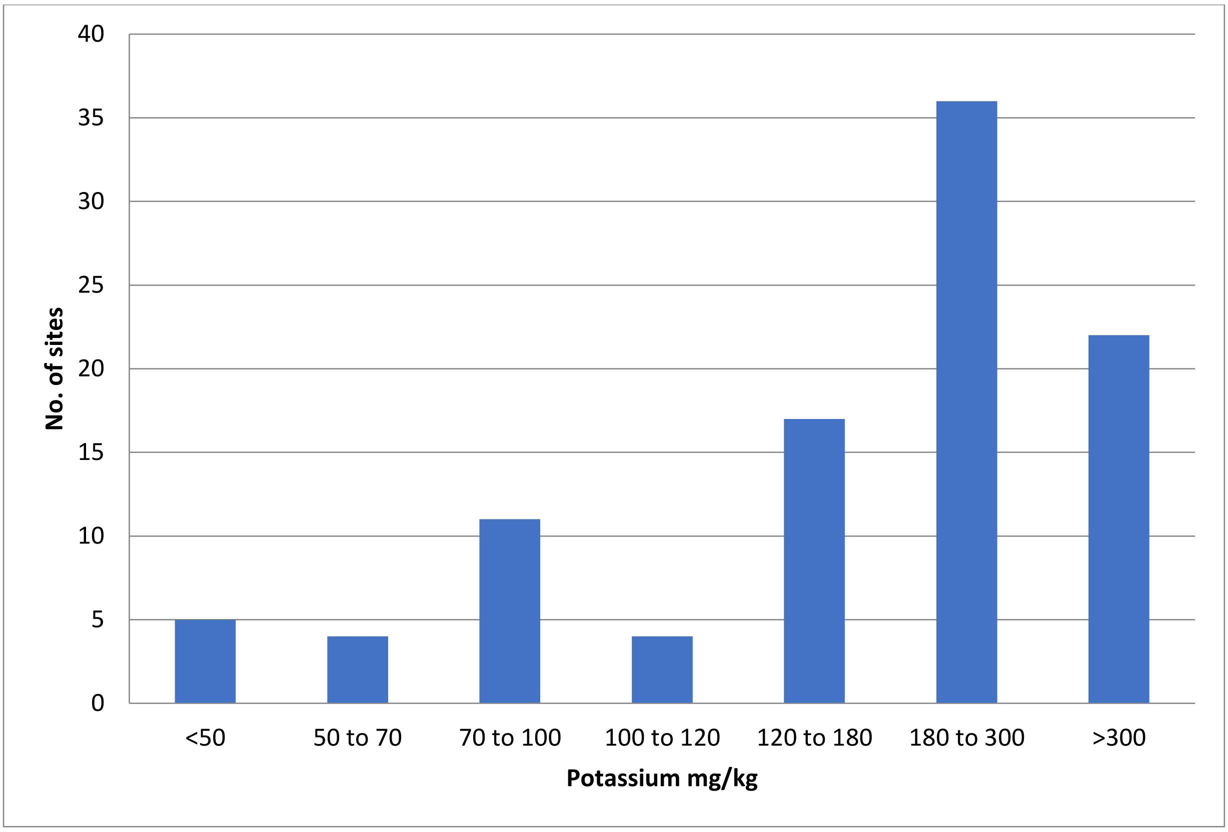

Figure 5: The frequency of the levels of soil potassium (Colwell) mg/kg at 0-10 cm from 100 sites.

Figure 7 shows the frequencies of different levels of potassium (Colwell). Most sites had levels between 128 and 226 mg/kg. Categories are from Botta (2016), and Dairy Australian (2019). Generally, the heavier the soil texture, the higher the optimum levels of potassium are (Botta, 2016).

3.6 Sulphur

Sulphur is a major mineral nutrient used in energy-producing processes by plants for growth, and indirectly a contributor to animal health (Botta, 2016; Department of Primary Industries, 1992).

Sulphur levels ranged between 3.2 mg/kg and 138.2 mg/kg, with a mean of 16.41 mg/kg. Sulphur soil levels above 8 mg/kg are required for achieving 90 to 95% potential pasture yield. Of the 100 sites, 19 were considered below optimal (less than 8 mg/kg).

Sulphur is considered a mobile nutrient and like potassium can be leached out of topsoils. Sulphur deficiency has generally not been an issue in the past as single superphosphate which contained sulphur was commonly used. With a change to high analysis fertilisers like MAP or DAP, which are low in sulphur, it is suspected that sulphur deficiency could increase.

As shown in Table 7, most sulphur deficient sites were lighter textured soils. The distribution of sulphur deficient sites across the Glenelg Hopkins CMA (Figure 8) does not indicate any obvious rainfall effect.

Table 7: Sites with sulphur levels less than 8 mg/kg and their texture at 0-10 cm.

Site ID	Sulphur (mg/kg)	Soil texture
1	7.6	Sand/loam
6	4.6	Sand/loam
7	5.8	Sand/loam
8	3.8	Loam
13	5.4	Loam/clay
23	6.6	Sand/loam
24	5.5	Sand/loam
26	6.4	Clay
33	7.8	Clay
49	5.6	Loam/clay
58	3.4	Clay
59	6.3	Loam/clay
61	3.2	Loam
66	7.4	Clay
67	7.6	Clay
89	7.2	Sand/loam
92	4.5	Clay
98	7.1	Sand/loam
99	5.1	Clay

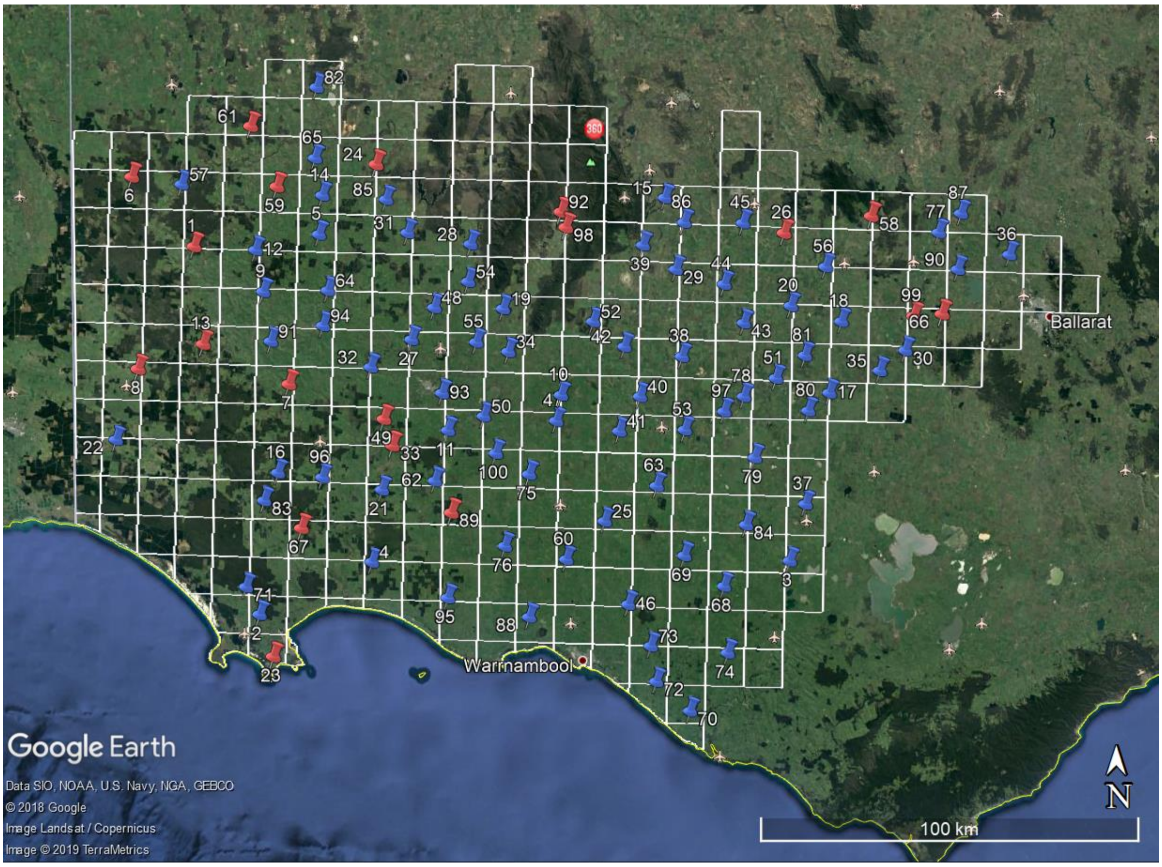

Figure 6: Red pins denote sites with low sulphur of the 100 sites sampled

Four of the 15 sites that had high sulphur levels (greater than 14 mg/kg) had had gypsum, a source of sulphur, applied one or more times in the last 4 years.

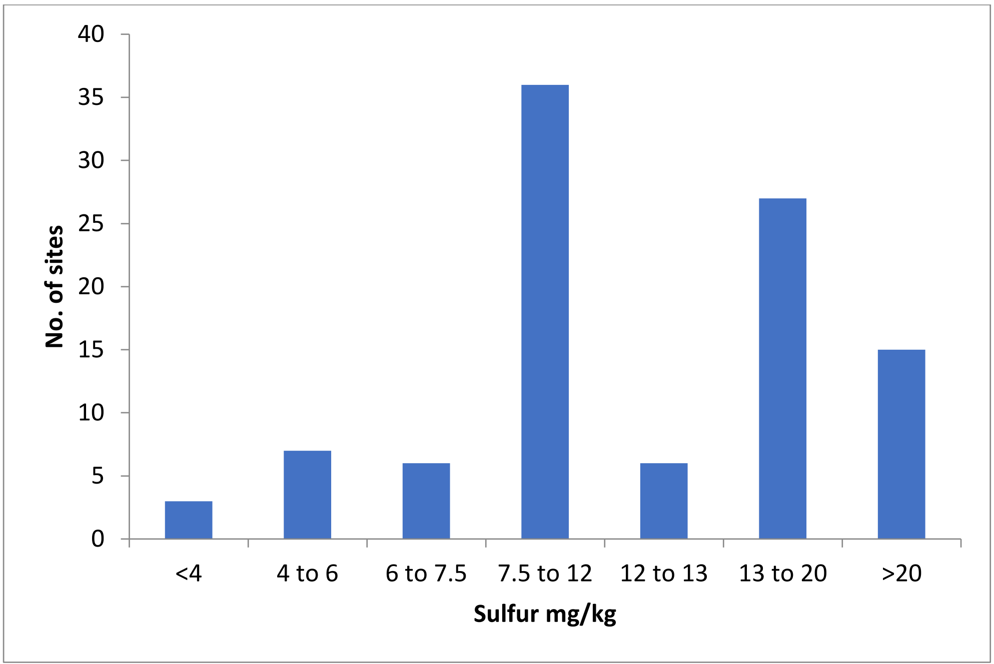

Figure 7: The frequency of the levels of soil sulphur mg/kg at 0-10cm from 100 sites across the Glenelg Hopkins catchment.

3.7 Soil pH ($CaCl_2$) and exchangeable aluminium

It should be noted that pH measured in $CaCl_2$ is used for the purpose of this report, as there is less seasonal variation in comparison to pH measured in water (Botta, 2016).

There are a number of critical soil pH levels which affect different plant and soil functions and the leaching of alkalinity from lime. These are shown in Table 8.

Table 8: Effects of different soil pH ($CaCl_2$)

Soil pH ($CaCl_2$)	**Effects of soil acidity**
5.5 to 6.0	There are no problems from soil acidity and there is net movement of lime beyond 10 cm depth.
5.0 or less	There is a chance of molybdenum deficiency in legumes. The effectiveness of rhizobia that fix nitrogen starts to become affected, especially acid sensitive legumes such as lucerne and pulses.
Less than 4.8	Soil aluminium starts to precipitate from a harmless solid into a toxic soluble form which affects root growth of pastures & crops. Aluminium tolerance among plant species varies.
Less than 4.5	Aluminium concentrations increase rapidly and quickly become toxic to most pasture and crop species as pH falls below 4.5. The speed of the Nitrogen mineralisation processes (Nitrification) slows.
Less than 3.8	Soil can no longer buffer against pH change and is overcome with acidity which breaks down clay minerals and irreversible structural damage is done.

Source: Table adapted from Planning on liming, NSW Agriculture, leaflet No 4 (2 Ed.).

(a) 0-10 cm

Soil pH (measured in $CaCl_2$) ranged from 3.9 to 7.3, with a mean of 4.9. Soils with pH below 6.5 ($CaCl_2$) are considered acidic, while those with a pH below 5.0 are generally considered likely to suffer production losses. Sixty-two of the 100 sites were below a pH of 5.0, indicating that most soils are strongly acidic in the 0-10 cm layer across the catchment.

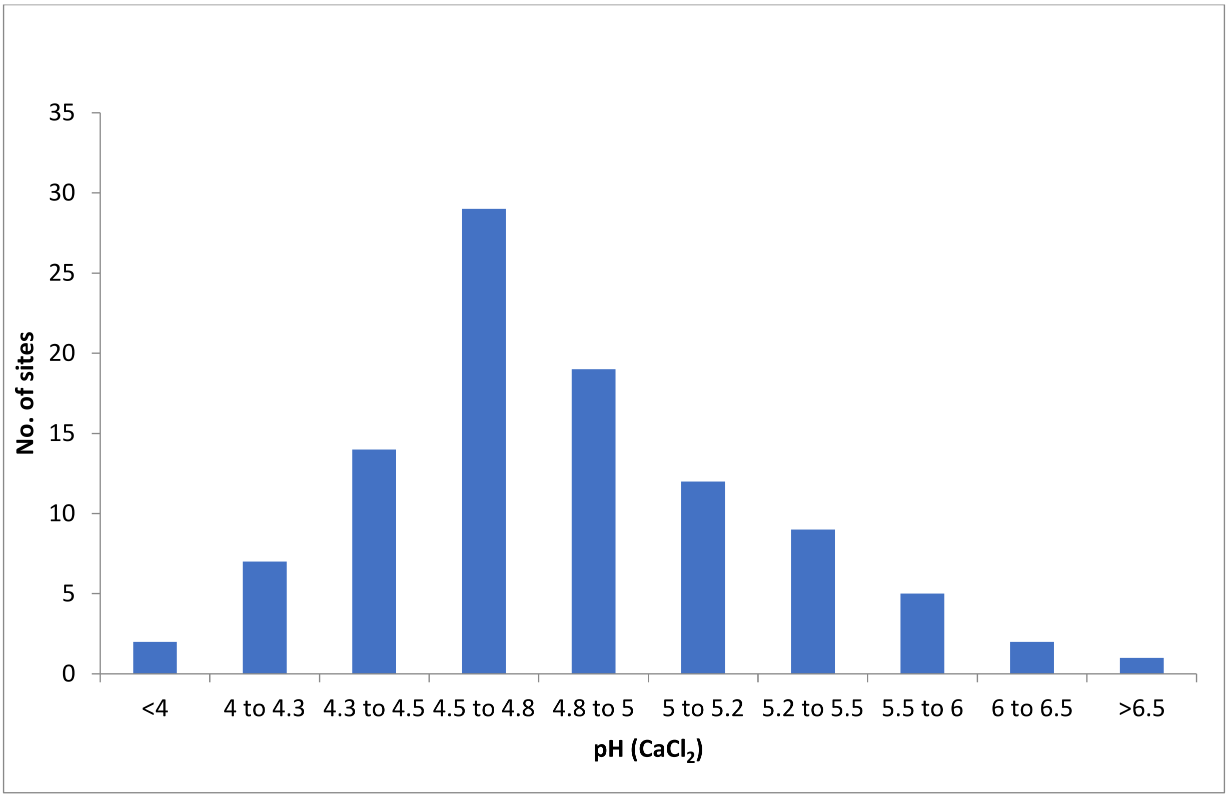

Figure 8: The frequency of soil pH ($CaCl_2$) from 100 sites.

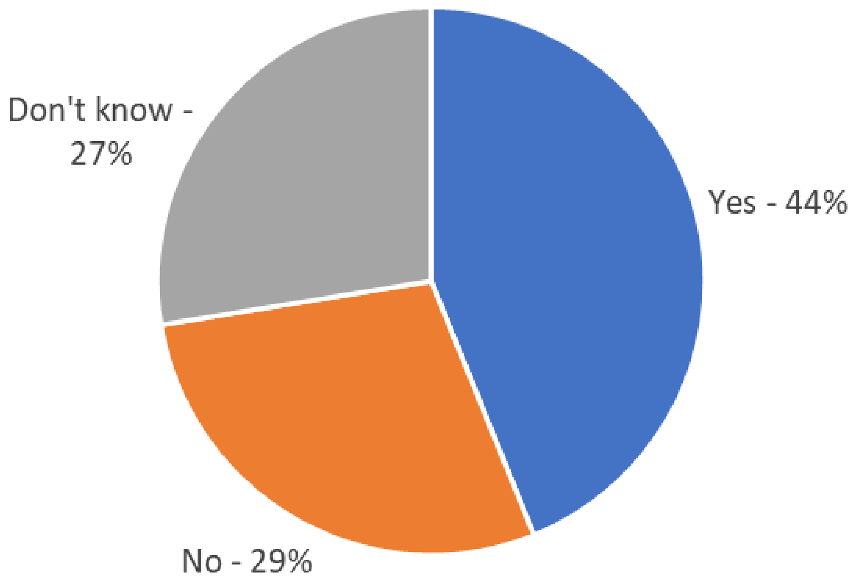

Figure 9: Growers responses to if topsoil (0-10 cm) acidity was a production constraint on farm.

Figure 11 shows that 43% of growers thought that topsoil acidity was a production constraint on their farm, however 62% of sites fell below pH 5.0, which is considered an issue for production, leaving approximately 20% of participants that may be unaware of potential production losses. 42% of sites fell below pH 4.8, which is the level where aluminium toxicity can become an issue and where the major plant nutrients (nitrogen, phosphorus and potassium) and the trace element molybdenum may have restricted plant availability (Botta, 2016).

Paddock history data obtained showed that 39 of the 100 sites had been limed one or more times in the last four years. Seven of the 39 sites had been limed two or more times, and three of the sites had been limed three or more times. The target pH in the topsoil (0-10cm) is greater than 5.5 if lime is to be surface applied and not incorporated. This is so there is enough lime or alkalinity to move below 10 cm. If topsoil pH is below 5.5, all the lime would be used up in the topsoil, and none of it would be available to ameliorate soil at depth (Miller, 2019; Victorian Department of Primary Industries, 2005).

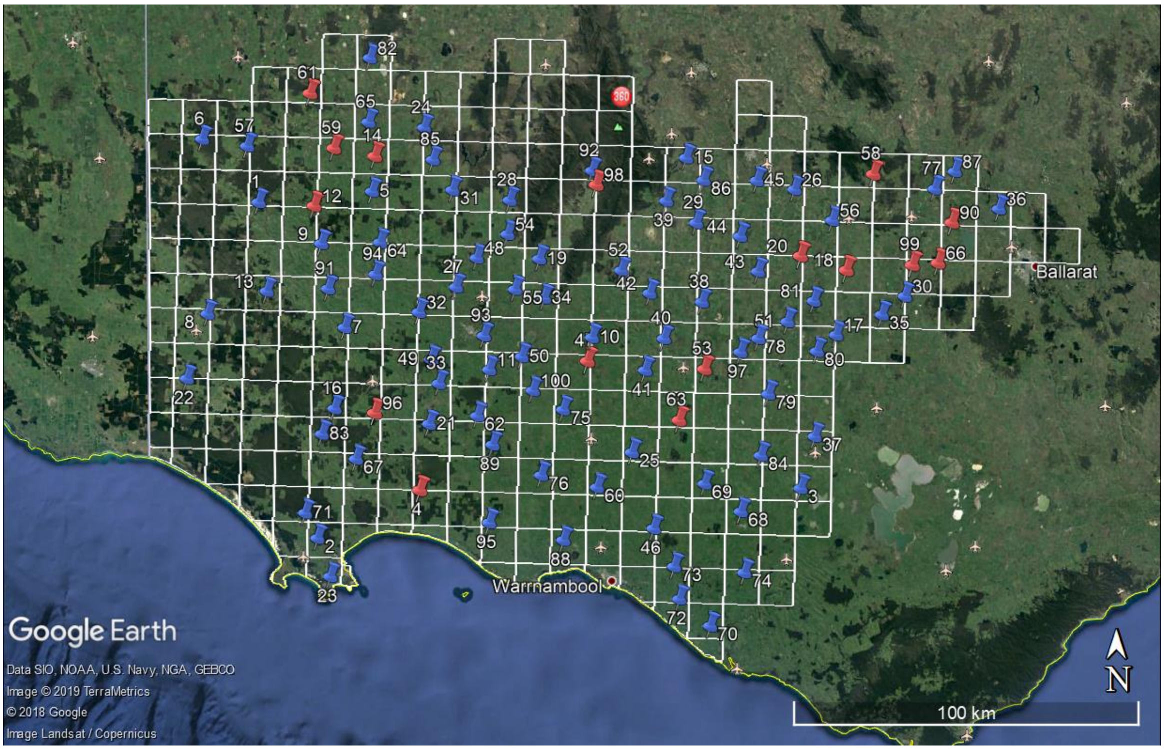

Figure 10: Red pins denote sites with extremely acid topsoil (0-10 cm) of pH 4.5 ($CaCl_2$) or less.

Figure 12 shows the sites where the topsoil is extremely acid (soil pH less than 4.5 $CaCl_2$). Table 8 below shows the locality, side ID and geology of the extremely acid sites. All but three of these sites are on either basalt, limestone or sand.

Table 9 shows the location of 16 sites with extremely acid topsoil. A range of parent geologies are represented, with clusters of sites appearing near Balmoral, Beaufort and Chatsworth.

Table 9: Localities, site identifications and geology of sites with extremely acid topsoils (soil pH <4.5 $CaCl_2$)

Locality	Site ID	Geology
Tyrendarra	4	Geology unknown
Mynamyn	96	Newer Volcanic Group - basalt flows
Nareen	12	Duricrust
Coojar	14	Loxton Sand
Tarrayoukya	59	Loxton Sand
Connewirricoo	61	Molineaux sand
Mirranatwa	98	Alluvium
Sth Penshurst	47	Newer Volcanic Group - basalt flows
Hexham	63	Newer Volcanic Group - stony rises basalt
Woorndoo	53	Duricrust
Streatham	20	Newer Volcanic Group - basalt flows
Stoneleigh	18	Newer Volcanic Group - stony rises basalt
Lake Goldsmith	99	Newer Volcanic Group - Basalt flows
Carngham	66	Pyrenees Formation
Burrumbeet	90	Newer Volcanic Group - Basalt flows
Raglan	58	Granite-Derived colluvium

(b) 10-20 cm and 20-30 cm

Soil pH is not regularly monitored below 10 cm by farmers unless lucerne is planned to be sown because it is highly acid sensitive. For this reason acidity at these depths can go unrecognised. The results for 10-20 cm tend to reflect those of 0-10 cm.

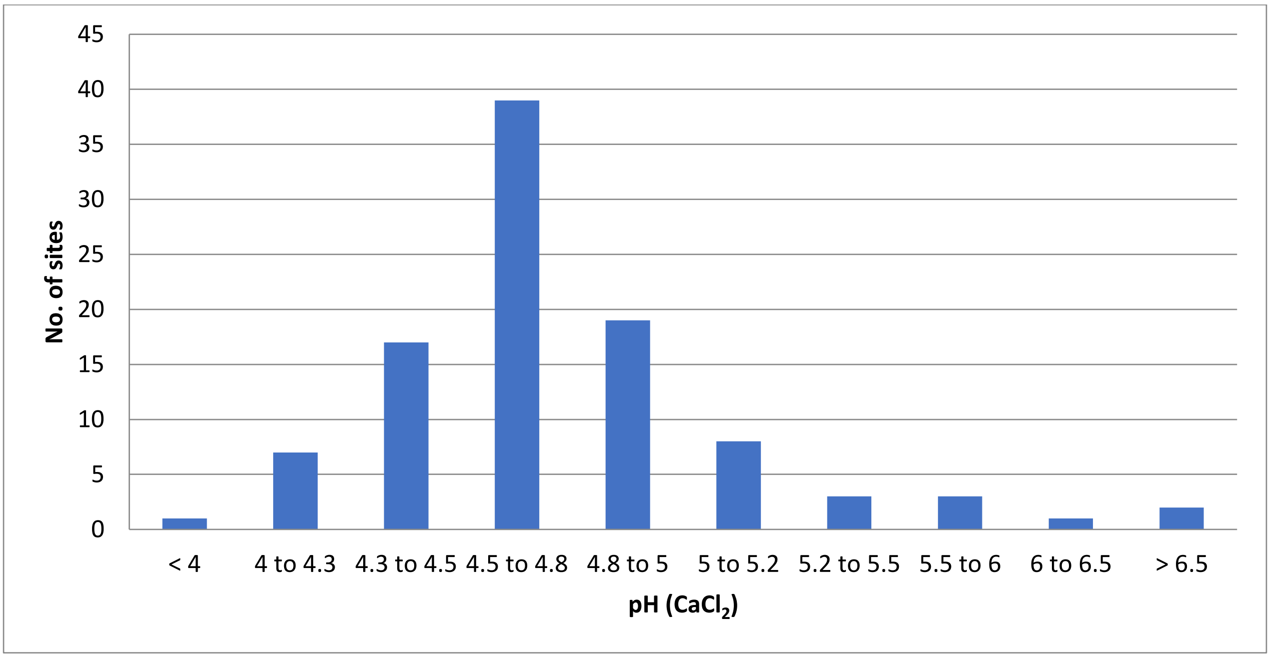

Figure 11: The frequency of soil pH ($CaCl_2$) at 10-20 cm from 100 sites.

Figure 13 shows that 52 of the 100 sites had a pH of less than 4.8 at 10-20 cm, which is considered an issue for production, particularly for legumes and acid sensitive plant species.

The subsoil often begins in the 20-30cm soil depth which is where clay content starts to increase. Generally soil pH starts to increase as free lime can be found particularly in basalt soils. Subsoil acidity is a concern because it is harder and more expensive to get lime to this depth. There were 27 sites which could be considered to have subsoil acidity (soil pH < 4.8). Further pH testing of intact deep cores by CeRDI will enable a better understanding of catchment subsoil acidity issues and what soil types or landscape zones are more likely to have subsoil acidity.

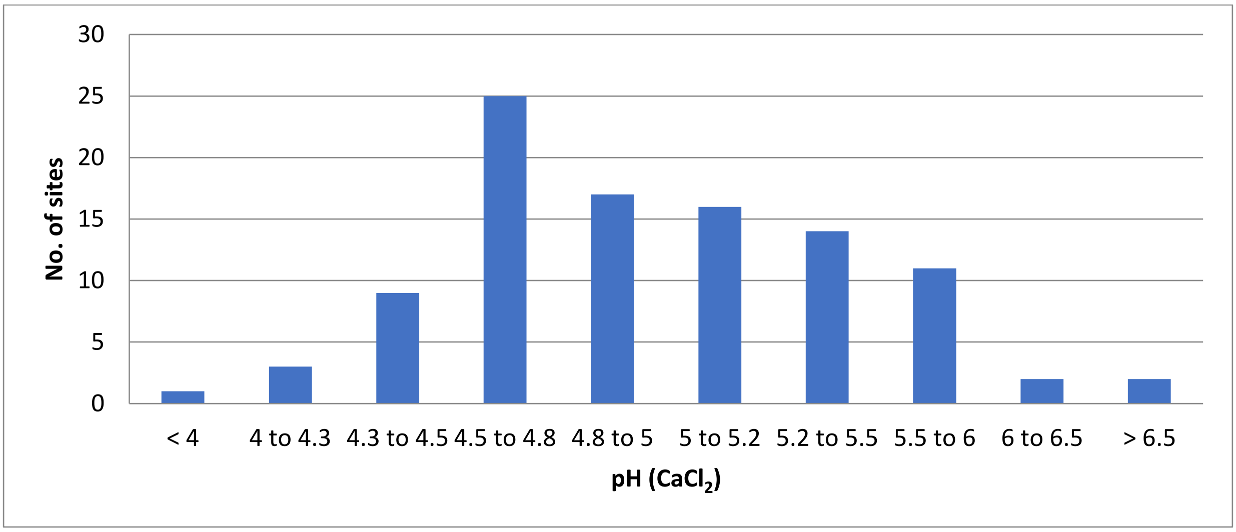

Figure 12: The frequency of soil pH ($CaCl_2$) at 20-30 cm from 100 sites.

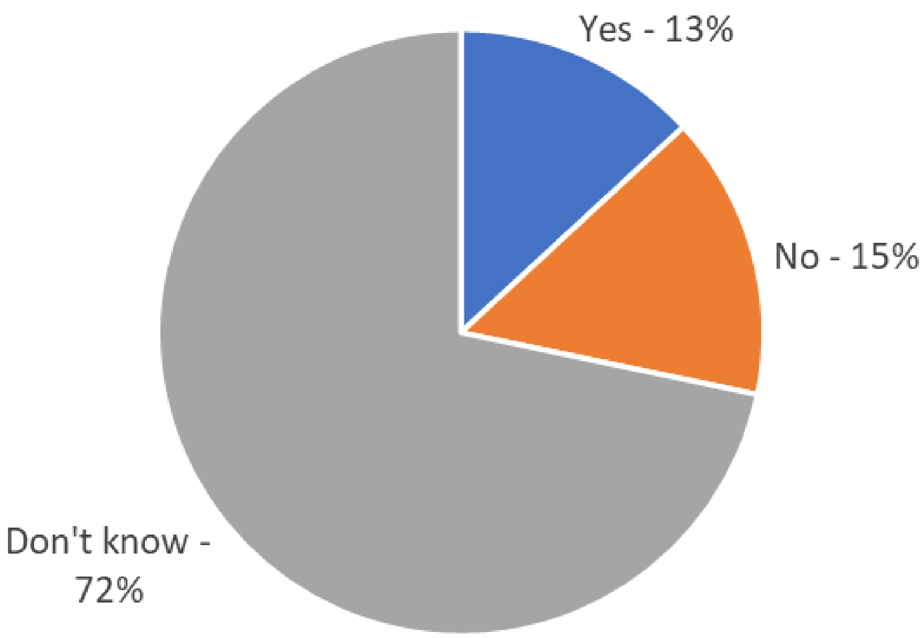

Figure 13: Growers responses to if subsoil (10 -30 cm) acidity was a production constraint on farm.

Growers were asked in their paddock history forms if subsoil (greater than 10 cm) acidity was a production constraint on their farm. The dominant answer "don't know" (Figure 15), was largely because most growers do not soil test below 10 cm.

(c) Exchangeable aluminium

At soil pH less than 4.8 ($CaCl_2$) aluminium ions come into solution, which are toxic to root growth and function. Lucerne is especially sensitive to aluminium (Botta, 2016). Aluminium toxicity has the potential to have a negative impact on the catchment as it can affect the survival of deep-rooted perennial grasses. Perennial grasses are particularly important over summer for ground cover, as they can help prevent erosion from wind and water, and the resultant loss of soil organic matter and nutrients into the waterways.

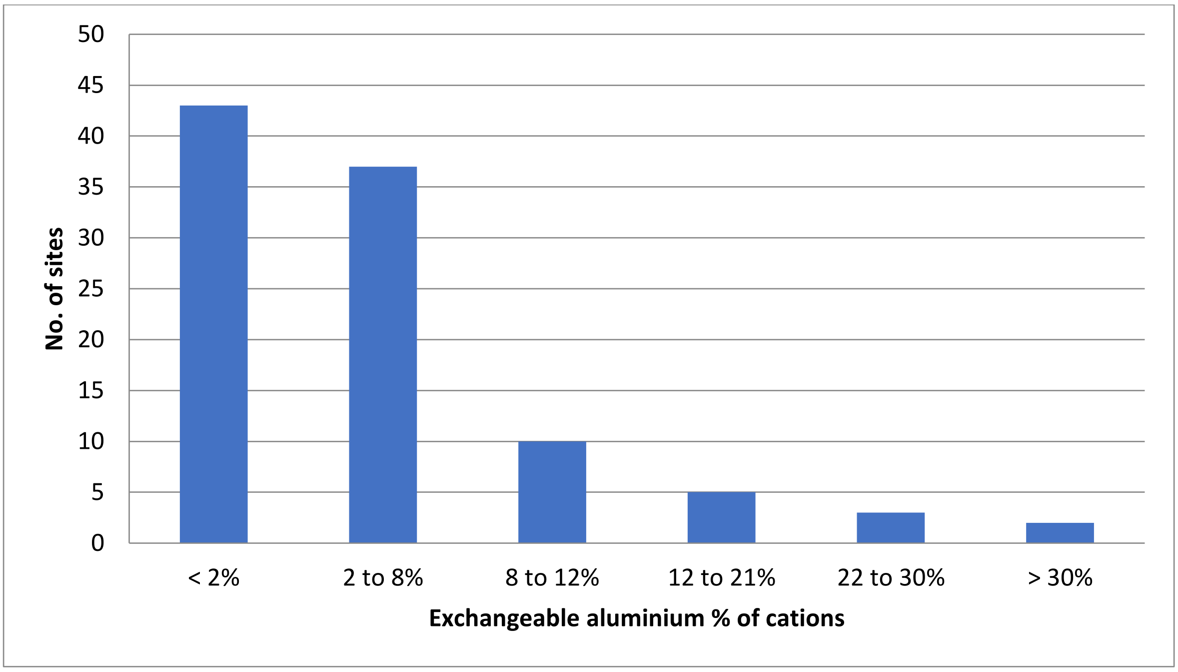

Figure 14: The frequency of levels of exchangeable aluminium % of cations in soil (0-10 cm).

The above categories in Figure 16 are adapted from Soil Acidity Monitoring Tools (DEPI, 2005), for "Medium Salinity" (EC 0.07 to 0.23 dS/m), as most sites fell into this category (Table 10). Highly sensitive plants are most likely to experience a 10% yield reduction between 2 and 8%.

The mineralogy within the catchment soils are not naturally high in aluminium and aluminium becomes a likely constraint to production when soil pH generally falls to levels of around 4.5.

Table 10: Critical concentrations of aluminium where plant growth is reduced for medium salinity (EC 0.07 to 0.23 dS/m) (DEPI, 2005).

Plant sensitivity to aluminium	Exchangeable aluminium (%)
Highly sensitive	2 to 8

Sensitive	9 to 12
Tolerant	13 to 21
Highly tolerant	22 to 30

3.8 Electrical conductivity

Electrical Conductivity (EC) measures free salts in the soil solution. It is commonly used to detect saline soils, but high salt content can also be caused through recent fertiliser applications.

The salt tolerance of agricultural crops is expressed in ECe which is the electrical conductivity of the saturation extract. Soils are classed as saline when ECe is above 4 dS/m, which is a level most plant species can be affected by. The ECe is obtained by multiplying the EC reading for its corresponding soil texture factor (Miller, 2019). When ECe was calculated, sites 68 and 79 had ECe levels estimated between 2.2 dS/m to 3.7 dS/m in soil layers from 0 to 30 cm. At these levels, possibly sensitive species like lucerne might be affected. This indicates these soils are likely to be slightly saline which would need to be confirmed by site inspection during late spring. Many black cracking clays which are often referred to as crab-hole soils are often slightly saline.

3.9 Exchangeable sodium

Generally, soils are classed as sodic when their clay particles contain greater than 6% exchangeable sodium (Na%). Sodicity can negatively affect aggregate stability which can impact air and water movement through the soil, plant emergence and make soils susceptible to erosion. Soil organic carbon provides a positive influence on aggregate stability and so dispersion tests of aggregates usually confirm aggregate stability. Dispersion tests are not reported in this report but will be reported with analysis of deep cores. The level of exchangeable sodium however provides an indicator of aggregate stability.

Good soil structure and aggregate stability results in more productive soils. As shown in Figure 17 below, 11 of the sites were considered to have sodic topsoil with an exchangeable sodium percentage of greater than six, which means they are prone to slaking and dispersion (Lemon and Hall, 2019).

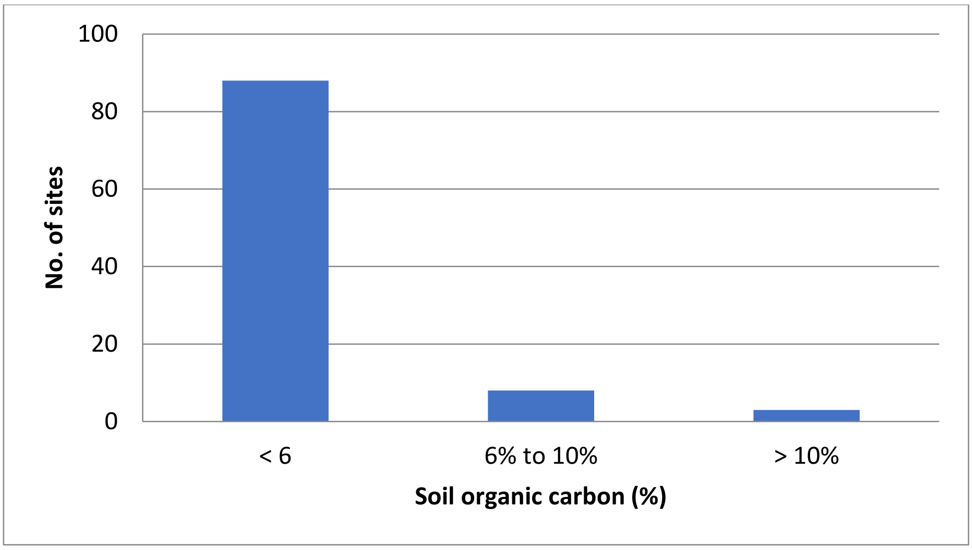

Figure 15: The frequency of exchangeable sodium % of cations in soil (0-10 cm).

3.10 Bulk densities

Bulk densities were taken as an indicator of soil health and for the potential calculation of tonnes of carbon per hectare.

Bulk density is the weight of soil in a given volume. When bulk density becomes higher than 1.6 g/cm^3, it begins to restrict root growth. Bulk density tends to increase with depth (Brown and Wherrett, 2019).

Table 10: Mean and standard deviation bulk densities for 0-10, 10-20 and 20-30 cm.

	Bulk density (g/cm^3)		
DEPTH	**0-10cm**	**10-20cm**	**20-30cm**
Mean	1.18	1.43	1.56
StDev	0.21	0.24	0.26

Table 10 shows the mean and standard deviations for the three different soil depths across the catchment. At 0-10 cm, three of the sites had bulk densities above 1.6 g/m^3. At 10-20cm, 22 of the sites had bulk densities above 1.6 g/m^3. At 20-30cm, 41 of the sites had bulk densities above 1.6 g/m^3. At these sites, there is the potential for root growth to be impeded due to compaction.

See Appendix 7.2 Bulk densities for an entire list of bulk densities at each individual site.

4.0 Conclusions

A soil benchmarking program has been successfully established within the Glenelg Hopkins catchment, which can be used to monitor catchment soil condition in the future.

Initial collection of baseline data shows the Glenelg Hopkins catchment to be dominated by strongly acidic soils with a higher amount of subsoil acidity (27 sites) than anticipated with confirmation to be provided by further analysis of intact soil cores taken to 80 cm depth.

Nutrient levels (phosphorus, potassium, sulphur) were generally not limiting production except for a minority of sites. Phosphorous levels remain higher than desirable from a catchment water quality perspective with 38 sites above phosphorus levels of 25 mg/kg. For future monitoring programs, the Phosphorous Buffering Index as a one-off additional measurement may be useful for reflecting the soil type’s ability to retain phosphorous which is influenced by minerology.

Total carbon levels were generally optimal with only 11 sites below total carbon levels of 2%. There was some evidence that continuous cropping had reduced carbon levels in comparisons with other enterprises and research literature suggests further declines would be expected under current management regimes.

5.0 Acknowledgements

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- Nathan Robinson, CeRDI for project support.
- Martin Peters, Trimble GPS support
- GHCMA supported by Australian government through NLP2

6.0 References

Agriculture Victoria (2016). Fertility targets suited to pasture and landscape, Australian Wool Innovation. Retrieved from: https://www.wool.com/globalassets/start/about-awi/publications/gd2097b-fertility-targets-fact-sheet_2-interactive.pdf

Agriculture Victoria (n.d.). Managing Phosphorus in Native Pastures, Australian Wool Innovation. Retrieved from: https://www.wool.com/globalassets/start/about-awi/publications/managing-phosphorous-in-native-pastures.pdf

Botta, C. (2016). Understanding your soil test step by step, Yeah River Landcare Group. ISBN 978-0-646-94804-1.

Brown, K., Wherrett, A. 2019. Fact Sheets Bulk Density – Measurement. Retrieved from: http://soilquality.org.au/factsheets/bulk-density-measurement

CCMA Soil Health Knowledge Base, 2019. Retrieved from https://www.ccmaknowledgebase.vic.gov.au/soilhealth/soils_map.php#

Dairy Australia (2019). Dairy Soils and Fertiliser Manual, retrieved from http://fertsmart.dairyingfortomorrow.com.au/dairy-soils-and-fertiliser-manual/

Department of Primary Industries (1992). Plant nutrients in the soil, NSW Government. Retrieved from: https://www.dpi.nsw.gov.au/agriculture/soils/improvement/plant-nutrients

Grains Research and Development Corporation (2014). Soil testing for crop nutrition, 2018. Grains Research and Development Corporation. Retrieved from www.grdc.com.au/GRDC-FS-SoilTestingS

Greenwood, K., Rees. D., Davey, M., Brown, A. (2008) Final Report HDLN Soil and Water Dairy Action Program – Soil Assessment Component, Department of Primary Industries, Kyabram & Werribee. Retrieved from: http://vro.agriculture.vic.gov.au/dpi/vro/coranregn.nsf/pages/coran_lwm_heytesbury_dav12222

Hobley, E., Wilson B. (2016). The depth distribution of organic carbon in the soils of eastern Australia. https://doi.org/10.1002/ecs2.1214

Hoyle, F. (2013). Managing soil organic matter – a practical guide, Grains Research and Development Corporation, Department of Agriculture and Food Western Australia. Retrieved from: https://grdc.com.au/__data/assets/pdf_file/0029/107696/grdc-guide-managingsoilorganicmatter-pdf.pdf.pdf?utm_source=website&utm_medium=download_button&utm_campaign=pdf_download&utm_term=National;%20North;%20South;%20West&utm_content=Managing%20Soil%20Organic%20Matter:%20A%20Practical%20Guide

Lemon, J., Hall, D. 2019. Dispersive (sodic) soils: the science. Retrieved from https://www.agric.wa.gov.au/dispersive-and-sodic-soils/dispersive-sodic-soils-science

McCaskill, M., Mitchell, M., Armstrong, R., Dunsford, K., Briggs, S., (n.d.). Five sweet spots of P application. Agriculture Victoria.

Miller, L. 2019. Pasture Target Levels for Soil Condition and Nutrient Level. http://www.sfs.org.au/SoilAcidityLimeResponse

Scanlan, C. (2015). Diagnosing potassium deficiency in wheat. Retrieved from https://www.agric.wa.gov.au/mycrop/diagnosing-potassium-deficiency-wheat

Summers, R. and Weaver, D. (2018). Environmental impact of nitrogen and phosphorus fertilisers in high rainfall areas. Department of Primary Industries and Regional Development, Government of Western Australia. Retrieved from https://www.agric.wa.gov.au/high-rainfall-pastures/environmental-impact-nitrogen-and-phosphorus-fertilisers-high-rainfall-areas

Queensland Government (2016). Soil texture. Retrieved from https://www.qld.gov.au/environment/land/management/soil/soil-properties/texture

Victorian Department of Primary Industries (2005). Soil Acidity Monitoring Tools. Retrieved from http://agriculture.vic.gov.au/agriculture/farm-management/business-management/ems-in-victorian-agriculture/environmental-monitoring-tools/soil-acidity

Victorian Government DEPI (2007). Making Better Fertiliser Decisions for Grazed Pastures in Australia. Retrieved from: http://www.asris.csiro.au/downloads/BFD/Making%20Better%20Fertiliser%20Decisions%20for%20Grazed%20Pastures%20in%20Australia.pdf

7.0 Appendices

7.1 Paddock history form

Glenelg Hopkins Catchment - Soil Benchmarking Project 2019

Paddock History

Farmers name (s)	Paddock name & location (e.g. road name)
Address	Email
	Phone
Paddock size	Date this form completed

Years ago (year)	**0** (2018)	**1** (2017)	**2** (2016)	**3** (2015)	
Cropping *Enter code*					0 = no crop, 1 = cereal, 2 = oilseed, 3 = grain legume, 6 = non-root vegetables, 7 = root vegetables, 8 = maize, 9 = sorghum, 11 = cereal hay
Crop Yield Tons/ha					Approximate value
Tillage *Enter code*					0 = Zero till (no working other than sowing), 1 = minimum till (1 working in addition to sowing), 2 = conventional till (2 or more workings)
Stubble management *Enter code*					0 = stubble retained on surface, 1 = stubble retained & worked in, 2 = stubble grazed, 3 = stubble baled and removed, 4 = stubble burnt *If more than one method, enter all that apply*
Pasture *Enter code*					0 = no pasture, 1 = annual pasture grass dominant (>75%) 2 = annual pasture - legume dominant (>75%), 3 = annual pasture - mixed grass/legume, 4 = perennial pasture - grass dominant (>75%), 5 = perennial pasture - legume dominant (>75%), 6 = perennial pasture - mixed grass/legume, 7 = mixed annual/perennial - grass dominant (>75%), 8 = mixed annual/perennial - legume dominant (>75%), 9 = mixed annual/perennial - mixed grass/legume
Pasture Yield Tons dry matter/ha OR					H = High pasture production, M= Medium Pasture Production, L = Low pasture production
Grazing management *Enter code*					0 = no grazing, 1 = set stocking, 2 = rotational grazing, 3 = mixture of set stocking & rotational grazing, 4 = other
Grazing animals *Enter code*					1 = sheep, 2 = dairy cattle, 3 = beef cattle, 4 = mixed or other
Cut for Hay (crop or pasture)					N = No, Y = Yes
Soil Testing *Enter code*					0 = no soil testing, 1 = soil pH only, 2 = full soil test, including pH
Fertiliser – Fertiliser type					
Fertiliser – kg/ha					
Soil conditioners *Enter code*					0 = none, 1 = lime, 2 = gypsum, 3 = other (please specify)

A few questions

Is soil acidity* (0-10cm) a production constraint on your farm?

Yes ☐ No ☐ Don't know ☐ (Tick ✓ or cross × the box)

Is sub-soil acidity* (>10cm) a production constraint on your farm?

Yes ☐ No ☐ Don't know ☐ (Tick ✓ or cross × the box)

** low pH*

Notes

Any other information about this paddock that you would like to add:

Please return this form to: Alice Debney at Southern Farming Systems
By post: 23 High St, Inverleigh, Vic. 3321,
By email: adebney@sfs.org.au

If you have any questions, you can contact Alice on: 0488 600 116

Thank you for completing the form and being involved in this project.

Once the form is received, Alice will call you to arrange a time with you to collect a soil core.

This project is supported by Glenelg Hopkins CMA though funding from the Australian Government's National Landcare Program

7.2 Bulk densities

Table 11: Soil bulk densities at each of the sites for 0-10cm, 10-20cm and 20-30cm (g/cm^3).

Site ID	Bulk density (g/cm3)		
	0-10cm	10-20cm	20-30cm
1	1.56	1.60	1.66
2	1.04	1.60	1.65
3	1.43	1.50	1.71
4	1.23	1.57	1.79
5	1.02	1.30	1.52
6	1.15	1.66	1.96
7	1.19	1.37	1.57
8	1.40	1.73	2.14
9	0.95	1.09	1.29
10	1.38	1.80	1.94
11	1.09	1.21	1.62
12	1.17	1.35	1.51
13	1.05	1.22	1.33
14	1.05	1.32	1.59
15	0.96	1.25	1.59
16	1.12	1.40	1.57
17	1.30	1.69	1.50
18	1.15	1.31	1.50
19	0.91	1.19	1.34
20	0.85	1.09	1.21
21	1.45	1.69	1.56
22	0.74	1.17	1.41
23	1.30	1.33	1.32
24	1.24	1.53	1.72
25	0.96	1.22	1.56
26	0.98	1.26	1.61
27	1.91	2.03	2.29
28	1.04	1.65	1.68
29	1.33	1.62	1.79
30	1.25	1.15	1.31
31	1.02	1.28	1.47
32	1.48	1.92	1.85
33	1.54	1.82	1.64
34	1.35	1.51	1.51
35	1.13	1.66	1.45
36	1.24	1.27	1.30
37	1.28	1.57	1.75
38	1.23	1.29	1.50
39	1.31	1.43	1.61
40	1.00	1.45	1.51

Site ID	Bulk density (g/cm^3)		
	0-10cm	10-20cm	20-30cm
41	1.12	1.48	1.35
42	1.10	1.12	1.26
43	1.18	1.28	1.41
44	1.24	1.23	1.19
45	0.90	1.20	1.26
46	1.31	1.26	1.37
47	1.27	1.58	1.86
48	1.04	1.47	1.63
49	1.36	1.60	1.81
50	1.21	1.39	1.59
51	1.11	1.25	1.32
52	0.91	1.16	1.14
53	1.12	1.79	1.97
54	1.07	1.29	1.21
55	1.19	1.63	1.80
56	1.32	1.51	1.51
57	1.33	1.57	1.49
58	1.00	1.35	1.44
59	1.03	1.40	1.71
60	1.26	1.52	1.93
61	1.22	1.49	1.75
62	1.79	2.03	2.20
63	1.01	1.11	1.33
64	0.91	1.16	1.35
65	1.01	1.44	1.68
66	0.88	1.38	1.78
67	1.21	1.44	1.70
68	1.01	0.97	1.13
69	1.23	1.35	1.41
70	1.28	1.58	1.74
71	1.26	1.58	1.79
72	1.37	1.52	1.60
73	1.43	1.44	1.50
74	0.95	1.21	1.45
75	0.85	0.93	1.08
76	1.33	1.68	2.25
77	1.09	1.28	1.57
78	1.17	1.17	1.18
79	1.07	1.01	1.04
80	1.61	1.69	1.72

Site ID	Bulk density (g/cm³)		
	0-10cm	**10-20cm**	**20-30cm**
81	1.11	1.37	1.58
82	1.21	1.49	1.99
83	1.29	2.12	1.81
84	0.96	1.29	1.58
85	1.25	1.40	1.49
86	1.32	1.63	1.77
87	1.31	1.19	1.26
88	1.46	1.38	1.66
89	1.47	1.69	1.75
90	1.09	1.29	1.38
91	0.94	1.12	1.28
92	1.04	1.41	1.40
93	1.56	2.05	1.69
94	1.36	1.62	1.59
95	1.12	1.48	1.64
96	1.19	1.51	1.80
97	1.26	1.45	1.43
98	1.02	1.45	1.47
99	0.82	1.17	1.38
100	0.65	0.81	0.71