Low Input Viticulture –
A Case Study from the
Granite Belt Wine Growing Region

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Executive Summary

This report presents a comparative case study evaluating low input viticulture against a conventional vineyard system in the Granite Belt wine growing region, with a primary focus on soil condition and functionality. The study was undertaken to assess whether low input practices can maintain productivity while improving soil health and reducing reliance on external inputs. Of note, the case study was developed during one of the driest periods on record in the Granite Belt.

Two sites at Twisted Gum Wines (TGW), managed using regenerative principles, were compared with a nearby conventionally managed control vineyard with similar soil type and landscape position. Soil characterisation confirmed all sites were Brown Tenosols—sandy, low fertility soils with limited water holding capacity—providing a consistent basis for comparison. A comprehensive soil health assessment was conducted using the EcoVineyards Best Practice Management Guide, supported by laboratory analysis, field observations, and additional biological and physical indicators.

Results consistently demonstrated improved soil functionality under the low input system. Soil health scores were higher at both TGW sites compared to the control, with the best-performing TGW site scoring approximately 20% higher. Key improvements included substantially greater soil organic carbon and active carbon, indicating enhanced biological activity and soil organic matter cycling. These changes were supported by Tea Bag Index which showed substantially larger capacity to stabilise organic matter additions in conjunction with the capacity to rapidly decompose organic matter under ideal conditions. Further, the TGW site outperformed native vegetation as a comparative benchmark for stabilising organic matter whilst the Control site stabilised less organic matter than the native vegetation.

Higher organic matter levels at TGW were strongly correlated with increased cation exchange capacity, highlighting the role of soil carbon in increasing nutrient retention in inherently low-fertility sandy soils. Notably, nitrogen levels under the low input system were equivalent to or greater than those at the conventionally fertilised control, suggesting effective nutrient cycling through organic matter, legumes, and grazing management. Physical soil properties were also improved, with lower bulk density and higher porosity indicating better structure, infiltration capacity, and root growth potential.

Despite these improvements, the study identified only minor trade-offs. Increased soil organic matter contributed to temporary water repellence under very dry conditions and slightly greater soil temperature variability, though neither was assessed as a major limitation. Importantly, the low input system has not incurred either a yield or quality penalty whilst long-term Normalised Difference Vegetation Index (NDVI) points similar performance on average.

Overall, the findings indicate that low input viticulture can enhance soil health and system resilience in Granite Belt vineyards without reducing vine performance. While the results are based on a limited number of sites and should be considered indicative rather than definitive, they highlight the potential for regenerative practices to improve soil function, reduce input dependency, and support more sustainable vineyard management in the region.

1. Introduction

1.1. Overview

1.1.1 Background

This project was initiated through conversations with viticultural growers in the Granite Belt, particularly at Twisted Gum, around whether changes in soil management could improve water use efficiency and overall farm resilience. There is growing interest in low input or regenerative systems and whether they can maintain productivity while reducing reliance on fertilisers and other external inputs. Twisted Gum has operated for a number of years without synthetic fertiliser inputs and there is a strong perception that the system performs well under dry conditions. The purpose of this case study is to move beyond those observations and test whether soil-health-based management is contributing to improved soil function, nutrient cycling and water use efficiency. The project aims to provide practical, evidence-based insights that can support other growers considering these approaches in the region.

1.1.2 About Twisted Gum Wines

Twisted Gum Wines (TGW - https://twistedgum.com.au/) is located at Ballandean and grows a range of grape varieties (including Chardonnay, Verdelho, Semillon, Cabernet Sauvignon, Mourvedre and Black Muscat). The property is 40 hectares (ha) of which approximately three hectares is under vines. The remaining area is largely natural vegetation (open Eucalypt forest). Shiraz is grown at Site A and Grenache at Site B.

Water is sourced from rainfall and surface runoff collected in onsite dams. Annual rainfall averages from 740 – 770 mm/year.

The owners, Tim and Michelle Coelli, describe their system as being regenerative viticulture. Their management practices include:

- Mid Rows (MR) contain a permanent sward of diverse grasses, forbes and legumes which provide habitat to encourage beneficial insects and also help produce ideal conditions for an active soil microbiology.
- A small flock of dorper sheep periodically graze to improve nutrient cycling.
- Small vineyard blocks are surrounded by native bush and provide habitat for beneficial insects, birds, reptiles, etc.
- Periodic application of mulch Under Vine (UV) for soil fertility. The last application was in 2016.
- Do not apply chemical insecticides or herbicides.
- Does not use synthetic fertilisers.
- Do not cultivate the soil.

Based on the available aerial imagery (sourced from QImagery - Queensland Government) the property has been developed for horticulture since the mid-1980s (between 1982 and 1989).

1.1.3 About the Control

The control site is a 0.4 hectare block at a small commercial vineyard that grows Fiano and Chardonnay grapes based on standard practices for the Granite Belt wine growing region. Average annual rainfall is 770 – 800 mm/year.

Management practices are what can be considered standard for the region and include:

- Irrigation
- Nutrient application using synthetic fertilisers primarily via fertigation
- UV kept weed free via herbicide
- Single species monoculture in the MR (kikuyu).

The area has been developed for horticulture since 1955 (assessed from imagery available on QImagery).

1.1.4 Note on weather

This case study was developed during an extremely dry period in the Granite Belt. Rainfall data from BOM indicates that rainfall was in the lowest decile on record for the five months ending 30 April 2026 (Figure 1). Overall rainfall was below or very much below average throughout the 2025/26 growing season.

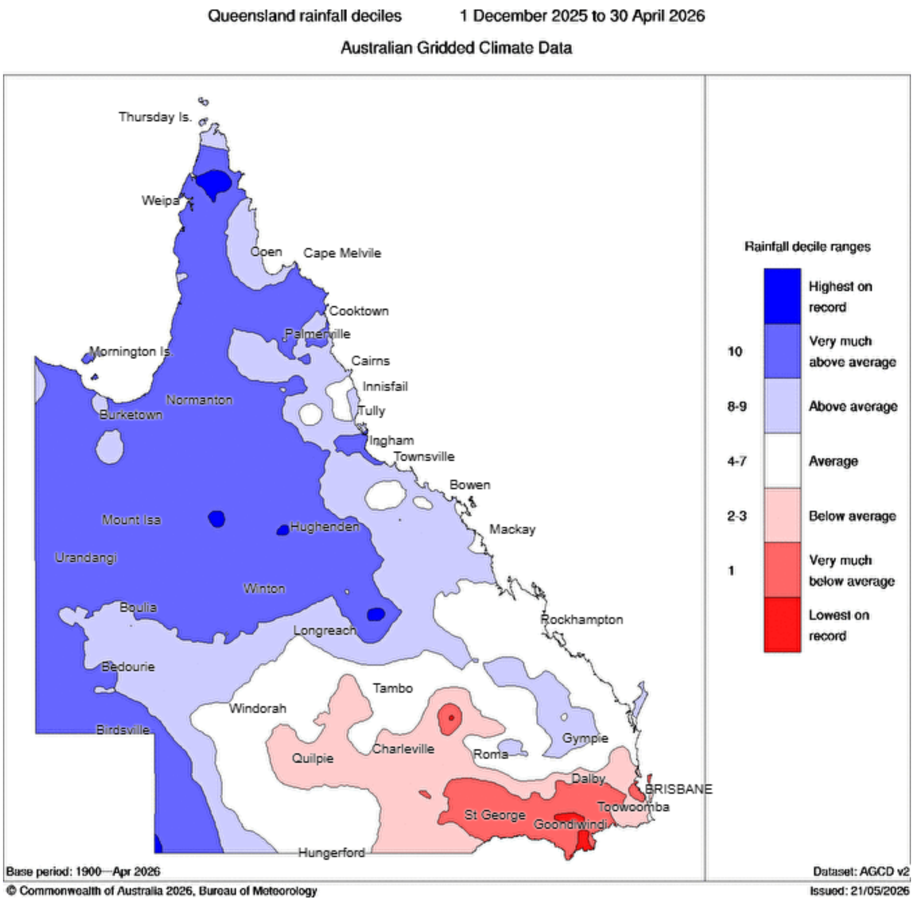

Figure 1 BOM Rainfall deciles for period 1 December 2025 to 30 April 2026 (five months). The Granite Belt is in the lowest on record decile. Source: [Recent and historical rainfall maps, Australian Bureau of Meteorology]()

Figure 2 provides historical rainfall data and the mean rainfall for the period 1 September to 19 June. This seasons rainfall (red line) is in the 2% decile. This highlights just how dry the conditions have been through the period in which this case study has been developed.

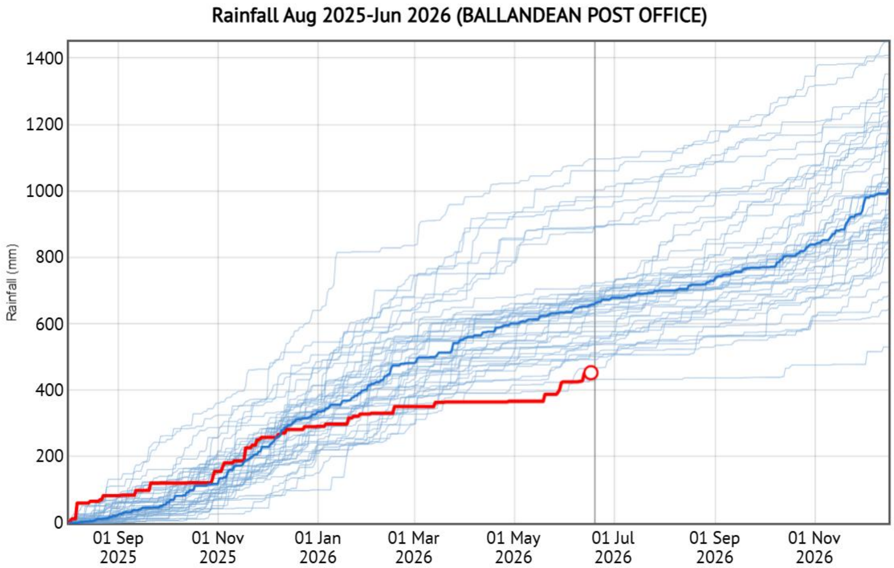

Figure 2 Rainfall for the Ballandean Post Office obtained from Australian CliMate (CliMate: How's the Season?) from 1 September 2025 until June 2026. Dark blue line represents average rainfall. Light blue lines represent previous annual rainfall. Red line indicates this season's rainfall.

1.1.5 Aim and Purpose

Aim. The aim of this Report is to document the findings of a comparative case study between a low input and conventional viticulture system with a focus on differences in soil condition.

Purpose. The purpose of the Report is to provide evidence as to whether low input viticulture is a viable option for wine growers in the Granite Belt.

1.2. Report Structure

This Report includes a description of the methodology applied, the results of the soil condition assessments, followed by a discussion.

1.3. Disclaimer

Soils and soil properties vary in multiple dimensions, being location, depth and time. Whilst all due care has been made in both the collection of soil samples and the interpretation of laboratory data it should be noted that soil samples were collected from specific sites and may not necessarily be representative at vineyard scale. Further the complexity of soil is such that the results from any particular management decision/action applied based on these results can vary considerably.

Publicly available data has been used to identify critical values for specific nutrients. Values for different crops, farming systems and locations may vary. The use of local calibration data, where available, is encouraged.

These factors should be considered if management decisions are to be made based upon the contents of this Report.

1.4. Funding Acknowledgement

This project was funded by the SQNNSW Innovation Hub. Funding for the Hub is provided by the Australian Government's Future Drought Fund. The activities of the SQNNSW Regional Soil Coordinator (RSC) are funded by the Australian Government's Natural Heritage Trust.

2. Methodology

2.1. Overview

This case study was developed based on the following approach:

- Identification of sites
- Soil characterisation using the Australian Soil Classification (Isbell and National Committee on Soil and Terrain, 2021)
- Completion of a soil health assessment primarily based on the EcoVineyards Best Management Practice Guide (Schapel and Retallack, 2024).
- Analysis and interpretation of results, including the differences in management practices.

2.2. Sites

Three sites were assessed. Two sites were selected at TGW to demonstrate the short-range variability that exists, even across a small vineyard. The first site at TGW (TG-A) was in an area of the vineyard that was better performing and the second site (TG-B) was in an area that was underperforming. The third site was a Control at a second vineyard to enable a comparison between low input and standard practice for vineyards in the Granite Belt. The major consideration in selecting the control site was that the soil type and landscape was similar to that at TGW. Soil mapping from Queensland Globe was used in the first instance to determine this followed by the characterisation of the soil to confirm.

2.3. Soil characterisation

The soil from each sampling site was characterised from a soil core collected in the Mid Row (MR). The cores were classified using the Australian Soil Classification (ASC) (Isbell and National Committee on Soil and Terrain, 2021). The classification was used to confirm the similarity of the soil at each of the sampling sites as well assist in interpreting the results of the soil health assessment.

A Honda-Christie post hole rammer and 40mm internal diameter soil coring tubes were used to extract the cores for description and classification.

2.4. Soil health assessment

2.4.1 Best Practice Management Guide

The EcoVineyards Soil Health Best Practice Management Guide (BPMG) (Schapel and Retallack, 2024), funded by Wine Australia, has been specifically developed for monitoring soil health in vineyards. It includes a range of physical, chemical and biological indicators, including a scoring system to support monitoring. Indicators include both visual/physical observations as well as laboratory data. The purpose of the monitoring described in the BPMG can be used to develop an action plan to improve soil function with the aim of increasing vine performance.

The soil health assessment was completed on the Under Row (UR) at three sites (two sites at TGW (Site A and Site B) and one Control site).

This is the first known use of the EcoVineyards BPMG Soil Health Assessment in the Granite Belt.

2.4.2 Soil sampling

Three soil samples were collected at each site for chemical analysis (a total of nine samples). The samples were collected from:

- The UR topsoil (0-10 cm). A composite sample was collected using a foot probe and 25 sub-samples.
- The MR topsoil (0-10 cm). A composite sample collected using a foot probe and 25 sub-samples.
- The MR subsoil (20-30 cm). A composite sample was collected from four soil cores collected using the Honda-Christie post hole rammer and 40mm internal diameter soil coring tube.

2.4.3 Chemical Analysis

Samples for chemical analysis were processed by CSBP Soil and Plant Laboratory (Home | CSBP Lab). The 'Comprehensive plus PBI' package was selected. Active Carbon for the topsoil samples was also measured. The soil properties analysed are detailed in Table 2-1. The majority of the methods are proscribed in Rayment and Lyons (2011) which describes the standard procedures used for the chemical analysis of soil samples in Australia.

Table 2-1 CSBP Comprehensive + PBI Analytes

Analyte (Soil Property)	**Method**
Phosphorous (Colwell)	Rayment and Lyons Method 9B
Potassium (Colwell)	Rayment and Lyons Method 18A1
Sulfur (KCl 40)	Rayment and Lyons Method 10D1
Organic Carbon (Walkley-Black)	Rayment and Lyons Method 6A1
Active Carbon	Rayment and Lyons Method 6E1
Nitrate Nitrogen and Ammonium Nitrogen	Rayment and Lyons Method 7C2b
Electrical Conductivity	Rayment and Lyons Method 3A1
pH (water)	Rayment and Lyons Method 4A1
pH (calcium chloride)	Rayment and Lyons Method 4B4
Soil characteristics: soil texture and soil colour	In-house method

Boron	Rayment and Lyons Method 12C2
Trace elements (DTPA) Copper, Zinc, Manganese, Iron	Rayment and Lyons Method 12A1
Exchangeable Cations (without pre-wash) Calcium, Magnesium, Sodium, Potassium, Aluminium	Rayment and Lyons Method 5A4
Phosphorus Buffering Index	Rayment and Lyons Method 9I2C

2.4.4 Other analysis

Several other analyses were completed in addition to those included in the BPMG. These are explained below.

2.4.4.1 Soil Temperature Monitoring

Two sets of Meter Group Teros 12 soil moisture monitors were available. One was installed at TGW Site A and the other at the Control site. Each set had three individual moisture probes. The probes were buried approximately 5 cm under the surface in the UR with the metal probes facing downwards. The probes include a temperature sensor the data from which was used to conduct a comparison of the difference in soil temperature between the sites.

The time series data was analysed to identify if any noticeable trends in soil temperature based on UR management could be determined.

One limitation of the use of the monitors is that the orientation of the rows differed between sites which may have influenced the temperature results.

2.4.4.2 Tea Bag Index

A modified version of the Tea Bag Index (TBI) (Keuskamp et al., 2013) was applied as a simple, repeatable method for assessing organic matter decomposition and stabilisation that can be readily implemented on-farm. The TBI is a simple method for assessing organic matter decomposition and stability, which are key indicators of soil biological health.

The test includes burying green tea and rooibos tea bags around 8-10 cm underground. Green tea degrades rapidly whereas rooibos tea is slower to decompose. The tea bags are left in place for around 90 days. Upon retrieval they are dried and weighed such that how much of each type of tea has decomposed can be measured. The loss of green tea can then be used to determine the decomposition rate (*k*) whilst the loss of the rooibos tea can be used to determine the degree of litter stabilisation (*S*):

- k (unit day^{-1}). The rate at which the readily decomposable fraction of organic matter is broken down by soil microorganisms.
- S (unitless). The proportion of decomposing organic matter that is retained and incorporated into stable soil organic matter rather than being decomposed and lost as CO_2.

Because of the unavailability of the standard tea bags used to determine TBI, loose leaf green and rooibos tea was weighed into polyester jewellery bags. Five pairs of tea bags (e.g. a pair consists of one green tea bag and one rooibos tea bag) were buried at each site. Tea bags were buried in the MR and UV at both the Control and TG-A. Additionally tea bags were buried in some native vegetation in close proximity to TG-A.

Due to the dry conditions in the Granite Belt and the requirement for moisture to aid decomposition, the experiment was also completed in a controlled environment. Samples from both TGW Site A and the Control site UR surface soil were collected. Soil and a tea bag were placed into 100 mm length of drainage pipe (50 mm outside diameter) and watered regularly to aid decomposition (~10 mL every three days). Each site and tea type had five replicates.

An overview of the TBI experiments is provided in Table 2-2.

Table 2-2 TBI experiments

Site	Location	Method	Mass of tea buried	Comment
TGW	Site A UV	Field	8.6g including tea bag mass	
TGW	Site B MR	Field	8.6g including tea bag mass	
TGW	Native Vegetation	Field	8.6g including tea bag mass	For comparison with an unmanaged soil
Control	UV	Field	Green tea – 8.6g Rooibos – 5g (including mass of tea bag)	Ran out of rooibos tea
Control	MR	Field	8.6g including tea bag mass	
TGW	Site A UV	Laboratory	8.6g including tea bag mass	~10 mL applied every 2-3 days
Control	UV	Laboratory	8.6g including tea bag mass	

2.5. Yield and quality

Ultimately, whilst soil condition is important, it is the yield of grapes and their quality under a low input system that is of primary interest.

Whilst it is not possible to gain accurate data on yield, an estimate has been made from self-reported publicly available information from TGW and other local vineyards.

The receipt of awards has been used as an indicator of wine quality produced by TGW.

Normalised Difference Vegetation Index (NDVI) data derived from satellite imagery has been used as a proxy for photosynthetic synthetic activity (E.g. potential biomass production) differences between the TGW and Control sites.

3. Results

3.1. Soil classification

The soil at all three sites was classified as a Brown Tenosol. A Tenosol is a soil that has weak pedological organisation other than an A horizon (topsoil). Soil depth, as indicated by how deep the soil core could be inserted, varied considerably between sites. The control site was the deepest with soil at least one metre in depth. At TGW, Site A soil was around 75 cm in depth and 50 cm in depth at Site B. The soil was largely apedal (having no structure) other than very weak development in the topsoil at both TGW sites. This structure was related to increased root density and organic matter in the surface soil. The A horizon (surface) at both TGW sites was assessed as being much deeper than at the Control (22 cm and 28 cm versus 11 cm). This is assessed as being the result of increased rooting depth of the multi-species pasture planted in the MR at TGW compared to the monoculture kikuyu grass at the control. Soils were very sandy with fine gravel present throughout the profile. As measured by the hydrometer method, there was almost no clay present at any depth but some silt (in the range of 3 – 8%).

The land type at both TGW and the Control is mapped as 'Granite Rises – Uniform Sands' (Maher, 1996). Limitations of this land type include very low to low water holding capacity, low fertility, rapid drainage but the potential for water logging where hardpans (compacted layers) are present in the subsoil. This land type is suitable for irrigated and/or dryland horticultural crops on soils deeper than 45 cm.

3.2. Soil Health Assessment

The results of the soil health assessment for the UR topsoil for the three sites assessed is attached as appendix one. The unweighted sum of the raw scores (there is no weighting system in the BPMG) are as follows:

- TGW Site A – 48
- TGW Site B – 42
- Control – 40.

Both sites at TGW scored better than the Control. TGW Site A scored substantially (20%) better than the control whilst TGW Site B scored roughly similar to the Control. For the three sections in the BPMG (Soil Health Indicators, Soil Chemical Indicators and Nutrients) TGW Site A scored better than both TGW Site B and the Control.

The results are an indicator that the management system at TGW, particularly Site A, has better overall soil condition than the Control site. TGW Site B was an area of the vineyard that was underperforming yet still was still assessed as having higher soil function than the Control.

In the following commentary, several points of interest from the results are provided focusing on:

- Soil Organic Carbon
- Active Carbon
- Tea Bag Index
- Soil field texture grade and colour
- Cation Exchange Capacity
- Nitrogen
- Bulk density and porosity
- Penetration resistance
- Water Repellence
- Temperature
- Copper and sulfur
- Boron.

3.2.1 Soil Organic Carbon

SOC is a key indicator of soil condition given its importance to range of soil functions. The results for both the UR and MR are provided in Figure 3. Key observations:

- At both TGW sites, the UR SOC is noticeably larger than the MR, whereas the opposite is the case at the Control. This can be explained by the lack of compost/mulch on the UR at the Control whereas the MR has a perennial cover of grass.

- All four TGW topsoil samples have higher SOC than the two topsoil samples at the Control.
- From a tonnes per hectare perspective (chart not included), the differences are not as marked but the trends are the same. The higher bulk density values at the Control site even out some of the differences presented in Figure 3.

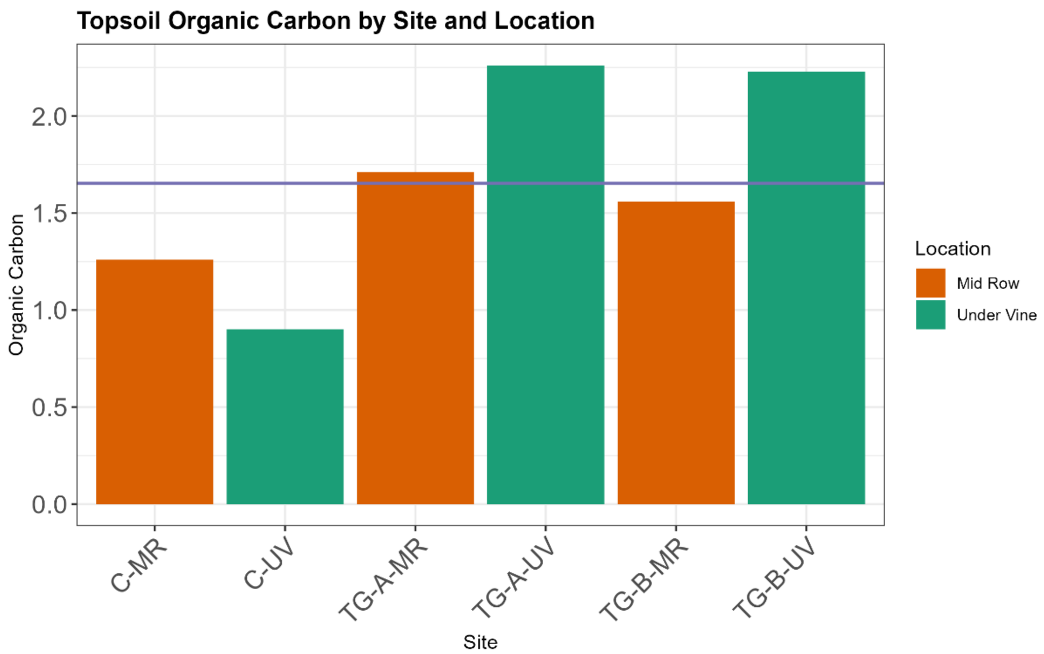

Figure 3 Topsoil (0-10cm) Soil Organic Carbon (%) as measured by the Walkley-Black method.

SOC from the MR subsoil (20-30 cm) depth increment was 0.41%, 0.64% and 0.4% respectively at TGW Site A, Site B and the Control. This is approximately 1% lower across all three sites compared to the MR topsoil. This large difference highlights the importance of the topsoil for soil fertility and function.

3.2.2 Active Carbon (POXC)

Active Carbon (Potassium Permanganate Oxidisable C (POXC)) measures a carbon fraction with unique molecular properties that may be an indicator of plant-mediated soil processes. These are typically phenolic and polyphenolic compounds (Christy et al., 2023). POXC has been recommended as a biological indicator for soil quality in both Australian (Riches et al., 2013) and overseas viticulture (Gonzalez-Maldonado et al., 2026). As a comparison, across 32 sites in California's Napa Valley, Gonzalez-Maldonado et al. (2026) found mean POXC levels of 592 mg kg^{-1} with a range of 117 to 1156.

No Australian or regional benchmarks are currently available however a global database of POXC values has been published (Chéron-Bessou et al., 2025). A subset of this database (arable land with comparable temperature and rainfall) has been extracted and used as a comparison.

The POXC results from this project are provided at Figure 4. At TGW the POXC values were higher than the mean from Gonzalez-Maldonado et al. (2026) at both UR sites with one of the MR sites also being higher and the other being close. The lowest POXC was in the UR at the Control (bare soil) followed by the MR (monoculture grass (kikuyu)).

These results are an indicator that the UR management and growing of a diversity of species in the MR at TGW has led to increased POXC in the topsoil, a positive indicator for soil quality.

Figure 4 Active Carbon (POXC) comparison

Using the benchmarks obtained from the global database of Active Carbon (POXC) results from (Chéron-Bessou et al., 2025) are provided in Table 3-1 Active Carbon (POXC) values and comparison against a globally comparable data.. All results with the exception of C-UV are rated as typical values. These results are quite impressive given both the sandy soil and extremely dry conditions prior to the sampling.

Table 3-1 Active Carbon (POXC) values and comparison against a globally comparable data.

Site	POXC_gkg	Percentile	Rating
C-UV	0.4043	28.1	Low
C-MR	0.5353	45.2	Typical
TG-B-MR	0.5508	46.4	Typical
TG-A-MR	0.6187	53.8	Typical
TG-B-UV	0.6693	57.7	Typical
TG-A-UV	0.6794	58.4	Typical

3.2.3 Tea Bag Index (TBI)

The TBI for the controlled experiment occurred over the period 1 March 2026 to 15 May 2026 and the field experiments occurred over the period 24 February 2026 to 10 July 2026 (136 days).

The results for S and k are provided in Figure 5 and Figure 6 respectively.

Notably, both TG field treatments exhibited stabilisation factors greater than those measured in the adjacent native vegetation site, whereas both conventional vineyard treatments exhibited lower stabilisation factors than native vegetation. This is an indicator that the soil at TGW promotes the formation of stable organic matter to a much greater extent than both the NV and Control. This suggests that the management system has enhanced carbon stabilisation beyond the native vegetation benchmark, while conventional management remains below this benchmark.

The relatively similar stabilisation factors observed under laboratory conditions suggest that environmental factors operating within the vineyard, including mulch cover, roots, microclimate and soil structure, contribute substantially to the enhanced stabilisation observed in the TG field soils. These findings are reinforced by the substantially higher SOC and Active Carbon concentrations measured at TGW Site A relative to the Control.

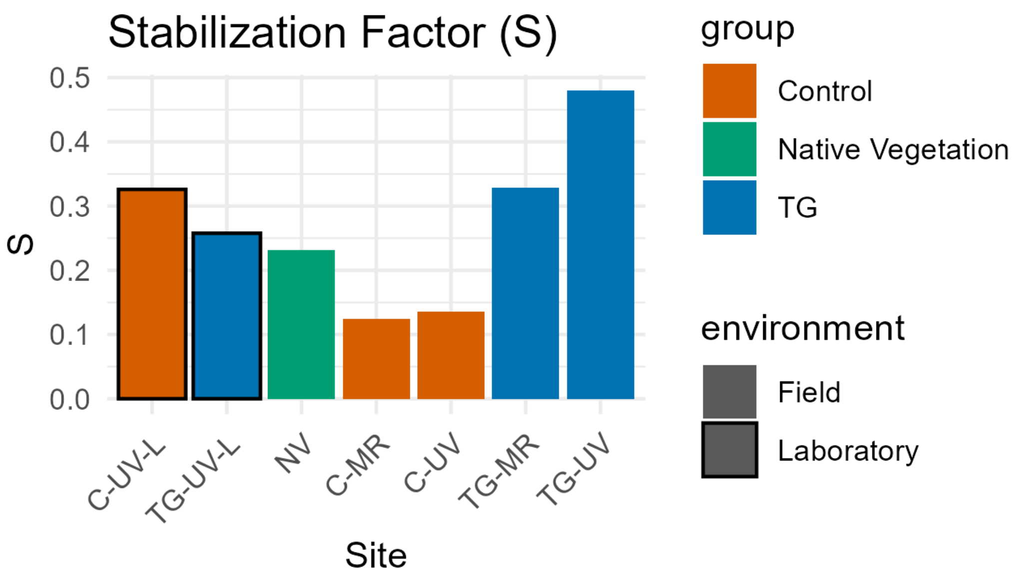

Figure 5 Stabilisation Factor (S) results from the TBI experiment. The laboratory results are bordered in black and the site colour coded (Control (C), Native Vegetation (NV), Twisted Gum (TG)). UV is the Under Vine and MR the Mid Row.

The highest decomposition rate for k occurs in the laboratory experiment for TG-UV. This is 3.5 times larger than that of the corresponding Control sample, seven times larger than the field result for TG-UV and 11 times larger than NV. These results suggest that the TG soil possesses a greater decomposition potential and is capable of rapidly processing fresh organic matter under favourable moisture and temperature conditions.

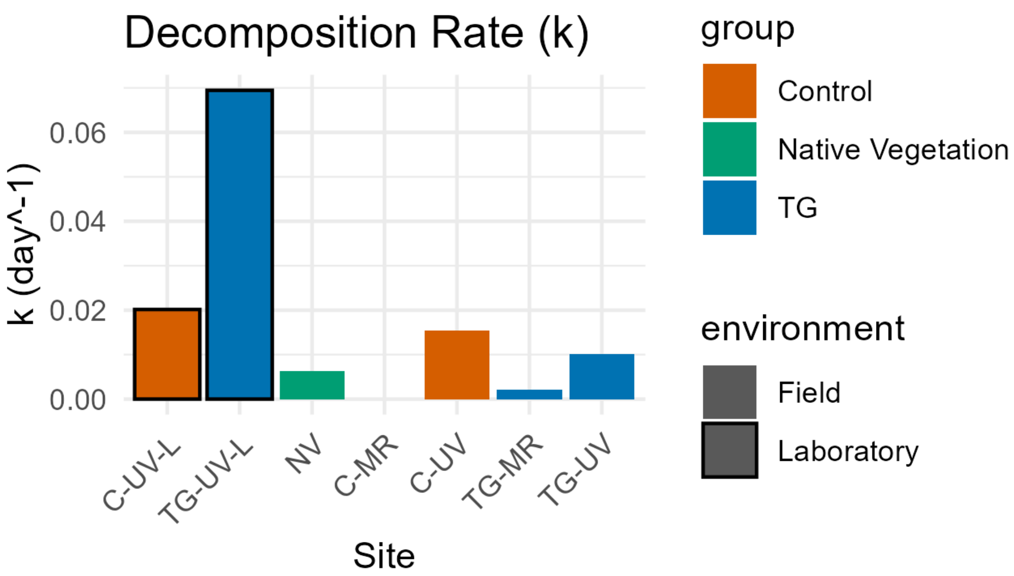

Figure 6 Decomposition rate (k) results from the TBI experiment. The laboratory results are bordered in black and the site colour coded (Control (C), Native Vegetation (NV), Twisted Gum (TG)). UV is the Under Vine and MR the Mid Row.

Overall, the TBI results indicate that the management system at TGW promotes greater stabilisation and retention of decomposing organic matter than either the conventional vineyard soils or the adjacent native vegetation. The laboratory incubations further demonstrated that TG soils possess a high decomposition potential under favourable moisture conditions, suggesting that enhanced carbon retention is not the result of reduced biological activity. Rather, the results indicate that the TG management system supports both active organic matter processing and efficient carbon stabilisation. These findings are consistent with the higher SOC, Active Carbon and nutrient status measured at TGW Site A and collectively suggest improved soil function and carbon sequestration potential under the management system at TGW.

3.2.4 Soil field texture grade and colour

During soil classification there was a noticeable difference identified in both the colour and soil field texture grade of the topsoil (0-10 cm) between the two sites used for the TBI experiment (TG-A and Control).

Using the Munsell colour chart system, the TG-A was slightly darker (black (10YR/2/1)) versus very dark gray (10YR/3/1) for the control.

Whilst the field texture grade for both sites was assessed as a loamy sand (a bolus was formed with slight coherence that formed a minimal ribbon) (National Committee on Soil and Terrain, 2024) the TG-A soil felt less coarse, made less noise when handling (noise created by the friction between sand grains) and made a slightly but consistently longer ribbon (approximately 10 mm versus 5 mm) than the control.

Note that the particle size analysis of these samples in the laboratory recorded 100% sand for the TG-A sample and 97% sand and 3% silt for the Control site.

These observable differences in colour and feel (field texture grade) can be explained by the greater amount of organic matter present at TG-A.

3.2.5 Cation Exchange Capacity

The soil texture, as measured by the hydrometer method, indicated very little clay and small amounts of silt across the three sites including with depth. The percentage of sand was typically greater than 90%. Sandy soils, being predominantly quartz, and hence non-reactive, typically has low Cation Exchange Capacity (CEC). CEC represents the capacity for the soil to store and exchange positively charged nutrients (cations) such as Calcium, Magnesium and Potassium and as such is an indicator of the fertility potential of the soil.

Increasing SOM is one approach to improving soil CEC as organic matter tends has a high CEC. A plot of SOC versus Effective CEC (ECEC) results (for all nine soil tests including both topsoil and subsoil) is provided in Figure 7. This shows a strong relationship between the SOC% and ECEC ($r^2 = 0.83$).

These results suggest that SOC levels are the primary driver of CEC in the sandy soils present at the sites. Further, although not measured, higher levels of SOC are also important for Anion Exchange Capacity (AEC). The AEC of bulk soil in general is low. Thus, the higher levels of SOM also enable anions, particularly mobile anions such as sulfate and nitrate, to be held in the soil.

Overall, these results are an indicator that management can lead to an increase in not only SOM but also ECEC, increasing the overall fertility potential of the soil.

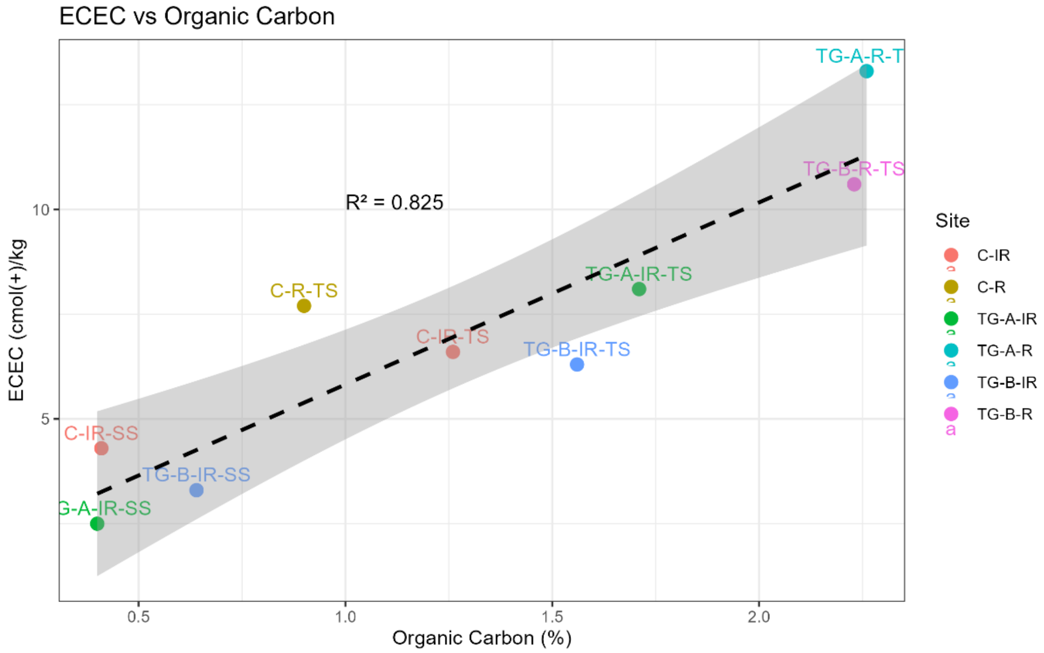

Figure 7 Plot of ECEC vs SOC for all nine soil samples collected. As there was negligible clay in all of the samples, the results are an indicator that the ECEC values are a function of the amount of SOC matter present.

3.2.6 Nitrogen

Total inorganic nitrogen (sum of nitrate and ammonium) results for the topsoil are provided in Figure 8. Despite no nitrogen fertilisers being added at TGW, the results for all tests are greater than or the same as at the Control.

The lowest result is at the Control MR which is a function of the presence of no legumes in the kikuyu monoculture pasture combined with no fertilisation. The Control UR, which is fertilised via fertigation has the same total nitrogen as the TGW Site A MR where the nitrogen is sourced from the mineralisation of SOM as well from legumes within the pasture sward and potentially from sheep urine during grazing periods. The two TGW UR sites had the highest level of nitrogen which aligns which both the highest levels of SOC and active carbon.

For the three subsoil samples collected the results were very low across all three sites (total or 2 to 3 mg/kg). This an indicator that the majority of nitrogen uptake is occurring from the topsoil.

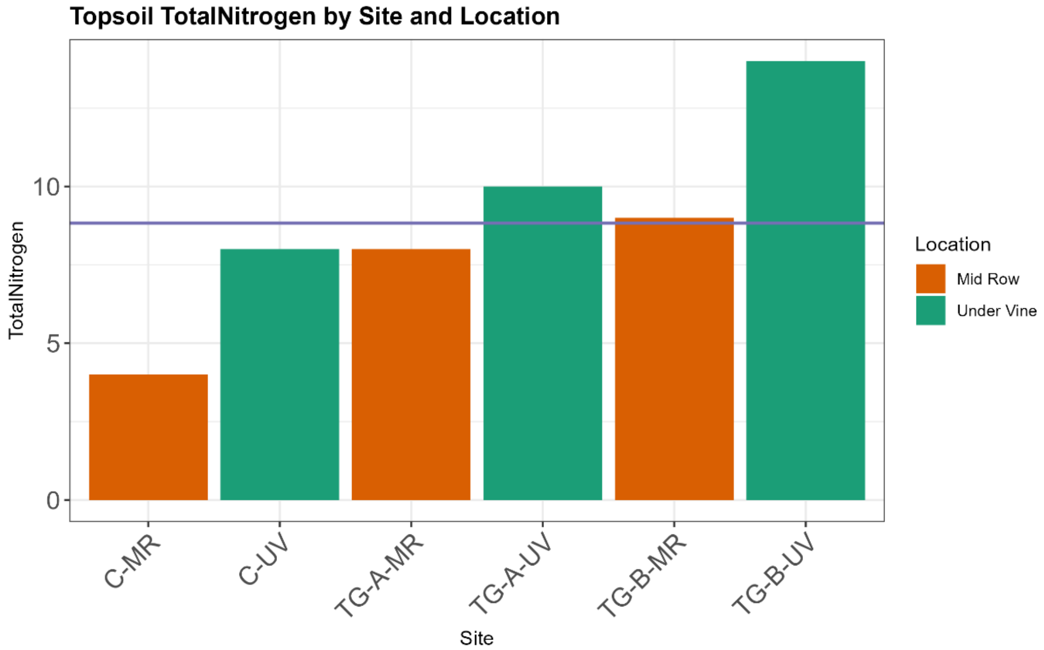

Figure 8 Total inorganic nitrogen (sum of nitrate and ammonium) for the topsoil (0-10 cm).

3.2.7 Bulk density and porosity

Bulk density is a measure of the level of compaction in the soil whilst porosity, which is mathematically related to bulk density, is a measure of how much pore space there is for gases and soil moisture to occupy. Typically, low bulk density and higher levels of porosity are preferred for soil functions including infiltration, water holding capacity and gaseous exchange and plant root proliferation.

Three bulk density samples were collected at each site in the UR and MR for the 0-5 cm depth increment in a 100 cm^3 cylinder. The average results are provided in Figure 9. Several observations can be made from the results:

- MR bulk density is greater than UR across all three sites although the difference at the Control is marginal.
- At both sites at TG, there is a relatively large difference between the UR and the MR with the MR being more compacted.
- The bulk density in the MR is similar for all three sites.
- The bulk density in the UR at both TG sites is substantially lower than that at the control. This is attributed to the substantially higher levels of SOM at the TG sites compared to the Control.

Figure 9 Bulk density results (0-5 cm)

3.2.8 Penetration resistance

10 measurements for penetration resistance (both depth of penetration and maximum pressure) using a penetrometer were taken at all three sites both in the UV and MR. Ideally this test is completed when the soil is at or near field capacity. Due to no recent rainfall the soil was very dry when these tests were completed.

The results are provided in Table 3-2 and Figure 10. There is a clear difference at all three sites between the UV and MR. Greater penetration being achieved with lower maximum pressure in the UV compared to the MR. This is to be expected as the UV is typically not trafficked by vehicles.

Table 3-2 Penetrometer results

Site	Position	Mean Penetration (cm)	Mean Maximum Pressure (kPa)
Control	UV	26.4	3060
Control	MR	12.8	5640
TG-A	UV	23.2	2060
TG-A	MR	13.4	5060
TG-B	UV	17.8	3360
TG-B	MR	11.2	5380

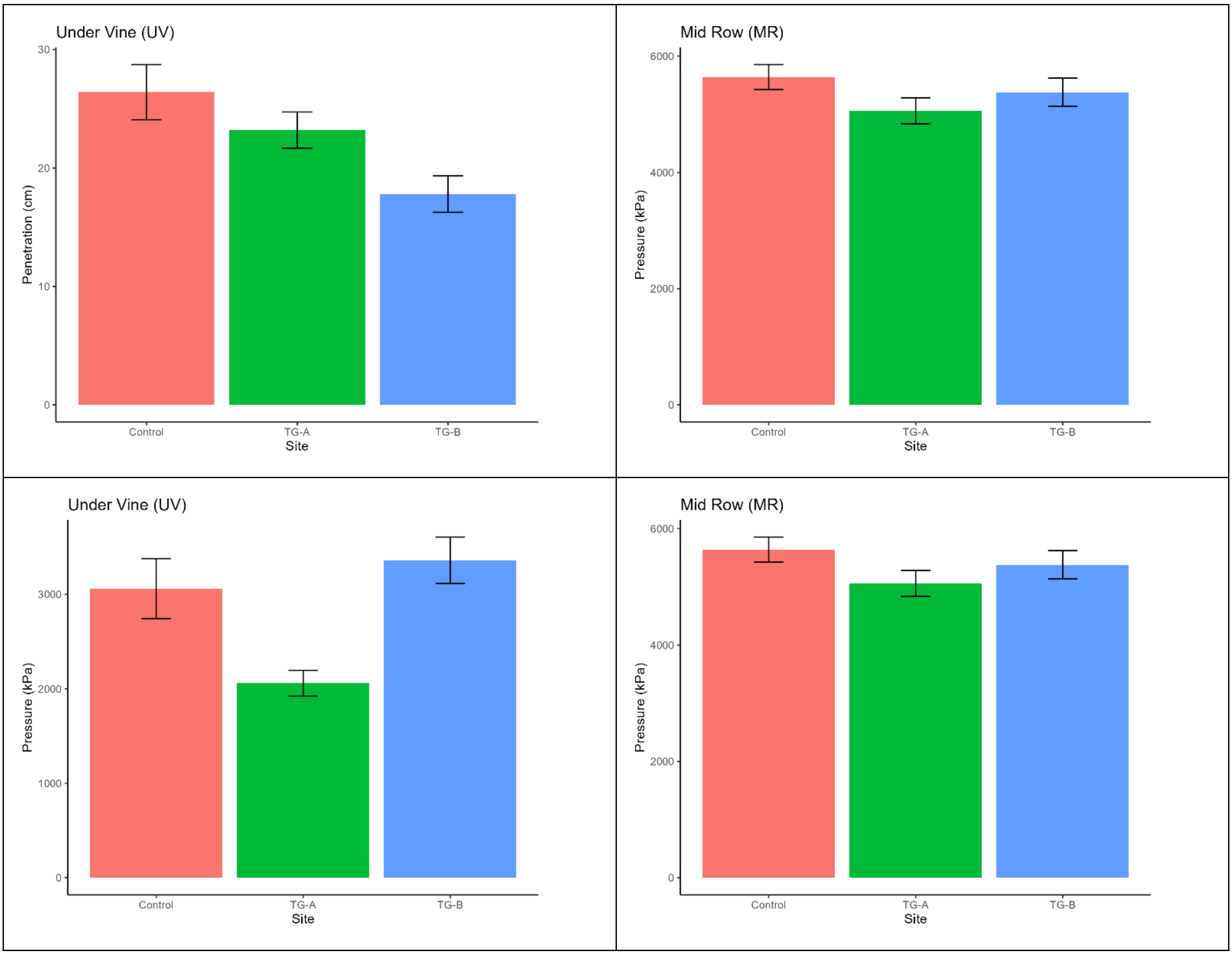

Figure 10 Results from penetration resistance tests for both the UV and MR. Top row is the depth of penetration (cm) and the bottom row is the maximum pressure (kPa).

The MR results (for both depth of penetration and resistance) across the sites are similar with no statistically significant differences. The UR results do vary however they are not conclusive (e.g. TG-A has the lowest maximum pressure but the Control has the greatest depth of penetration).

3.2.9 Water Repellence

During both the soil description and laboratory TBI experiment it was noted that there was water repellence at both of the TGW sites.

During classification it took several seconds for the drops of water to be absorbed on the MR surface horizon whereas the water was absorbed immediately at the control surface horizon and all subsoil horizons across the three classification sites.

During the initial stages of the TBI experiment, the water repellence for the TGW samples (from Site A) was quite pronounced with the water droplets beading for some considerable time (~30 seconds) for the first several times water was applied (approximately five waterings). There were no water repellence issues in the subsequent waterings.

The water repellence is assessed as being due to the very low levels of soil moisture present at the time of sampling (a consequence of the historically low rainfall in the lead up to sampling). The drying out of soil organic matter can lead to hydrophobic organic molecules re-orienting so that the water-repelling end faces outward resulting in the beading of water at the soil surface. This process is, as proven with the TBI experiment, reversible where sufficient rainfall or irrigation is applied.

3.2.10 Temperature

There are a range of different metrics by which soil temperature can be compared. Results from the soil moisture sensors have been used to determine hysteresis, Thermal Buffering Index, lag, extremes, and variability are presented below.

Hysteresis

Hysteresis refers to the phenomenon where the temperature response of a system (e.g. soil) lags behind changes in the heating or cooling input (e.g. air temperature). The soil temperature versus air temperature data for the period 17 February to 10 May 2026 for both sites are presented in Figure 11.

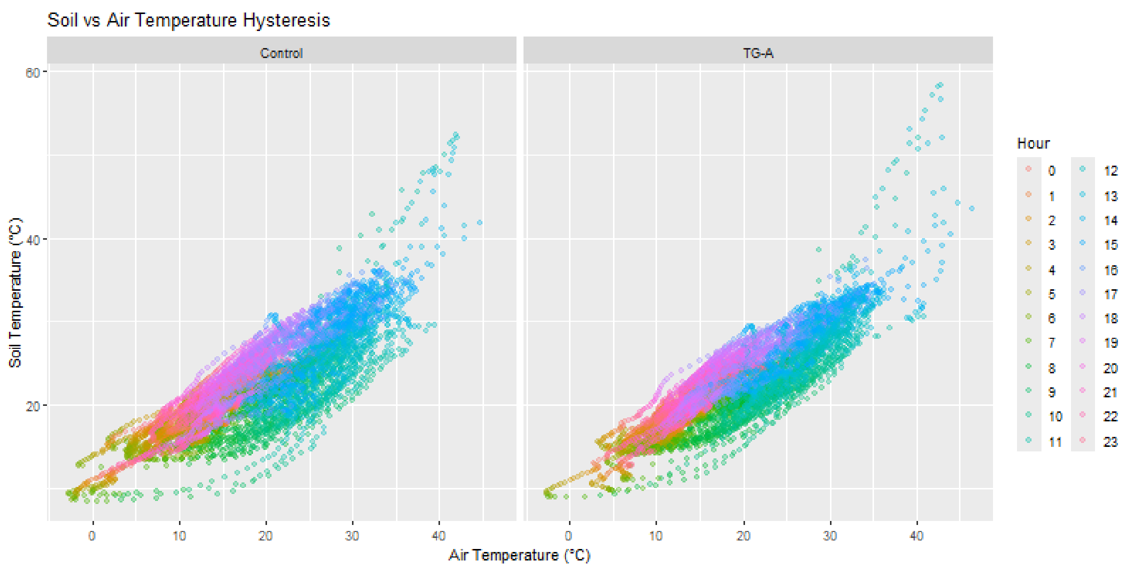

Figure 11 Plots of soil temperature versus air temperature. Control data is on the left and TG-A on the right. Colours represent hours (in 24-hour format).

The data for both sites shows a clear pattern of hysteresis with soil temperature lagging air temperature in the morning (green colours) then tending towards higher temperatures during the middle of the day (blue colours). As air temperatures cools in the afternoon and evening (pink colours) soil temperature tends to remain greater than the air temperature.

The results between sites are broadly similar. However, TG-A tends towards more extreme soil temperatures when the air temperature is also the most extreme. The reasons for this are explored later.

Thermal Buffering Index

The Thermal Buffering Index is the ratio of the daily soil temperature range (maximum minus minimum) divided by the daily air temperature range. It provides an indicator of the soils ability to resist changes in temperature. The TG-A site had a slightly larger mean thermal buffering index value compared to the control (1.1 versus 1.0). Whilst the difference is statistically significant (e.g. a real difference), the effect is small.

Lag

Soil temperature lagged air temperature at both sites, with the control exhibiting a longer lag (~1.75 hours) compared to the TG-A system (~1.25 hours). This suggests slower heat transfer in the control soil whereas the TG-A soil exhibits more rapid and dynamic thermal response consistent with improved aggregation and pore connectivity.

Temperature Extremes

The soil temperature under conditions of extreme air temperatures (threshold 30°C) was determined and the difference between the mean soil and mean air temperature calculated. The results are provided in Table 3-3, with only minor differences present.

Table 3-3 Temperature Extremes

Site	**Mean Air Temperature**	**Mean Soil Temperature**	**Delta**
Control	32.8	31.5	1.32
TG-A	32.8	31.8	1.08

Variability

The variability of soil and air temperature as measured by the Standard Deviation (SD) of each dataset is provided in Table 3-4.

Table 3-4 Soil and air temperature variability

Site	Soil Temperature (SD)	Air Temperature (SD)	Ratio
Control	5.33	7.49	71%
TG-A	5.06	7.24	70%

Both soil and air temperature is slightly less variable at TG-A compared to the Control. This could be a result of micro-climatic differences between locations, however the differences are only minor. The lower soil temperature SD at both sites provides an indicator of the buffering effect of soil on temperature changes. The ratio of Soil Temp SD/Air Temp SD is an indicator that the soil provides moderate buffering at both sites.

Temperature summary

Overall, the soil temperature results indicate only minor differences between the sites. The higher SOM at TG-A acts as a buffer against soil temperature changes just as the lower porosity/higher bulk density at the Control does. These counteracting trends, combined with the different vine row orientations, protective netting (Control site had nets covering each individual row whilst TGW nets covered blocks), and foliage density, may explain why no conclusive differences have been obtained from the soil temperature data.

Finally, the extremely dry conditions (no rainfall was recorded during the monitoring period), combined with the monitoring occurring after the growing season (e.g. no irrigation) are likely to have contributed to some of the more extremes of temperature as seen in the hysteresis results. Soil moisture levels average around 5% throughout the monitoring period meaning that there was effectively no buffering effect from moisture on changes in soil temperature.

3.2.11 Copper and sulfur

Copper based and sulfate products have been and are widely used in viticulture to prevent and/or minimise the damage caused by downy mildew and powdery mildew. As a result, both copper and sulfate can accumulate in the soil. Copper, whilst naturally occurring in the soil, typically at low levels, can become toxic at high levels. Sulfate is a mobile, and hence leachable, macronutrient so its presence in the soil is beneficial.

Figure 12 provides the standard laboratory test (DTPA) copper results. There are noticeable difference between sites with the results between the UV and MR being generally similar.

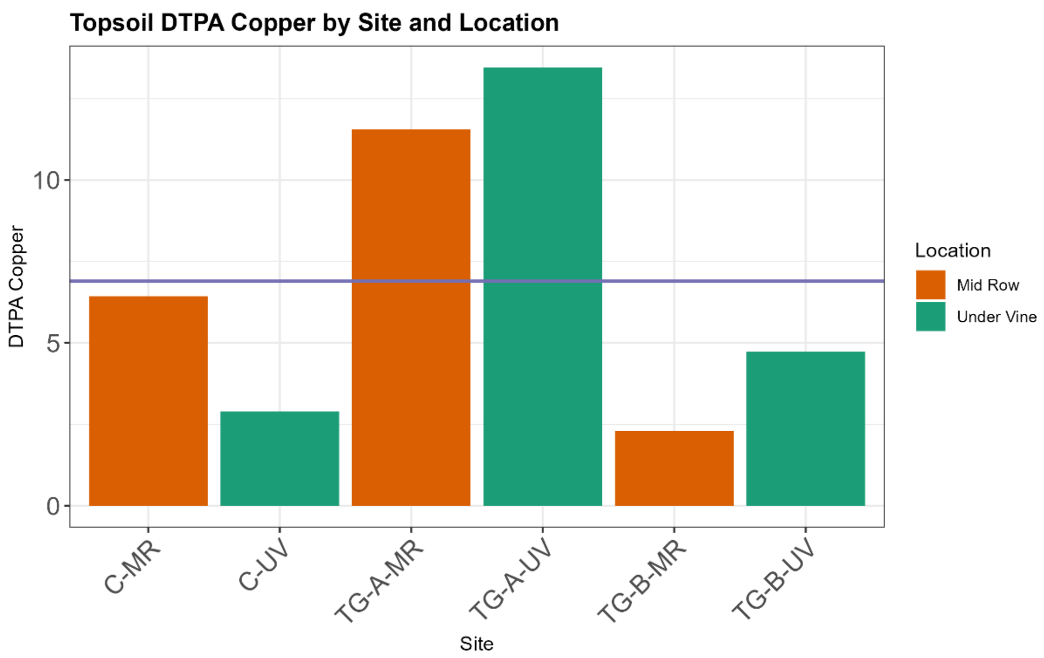

Figure 12 DTPA Copper (mg/kg)

Copper toxicity has typically been measured by total copper (compared with available copper which is what the DTPA method calculates). On average DTPA measures ~38% of total copper (Romić et al., 2014). An estimate of total copper has been made by dividing the DTPA copper amount by this value with the results provided in Figure 13. These results are as low, and in most cases much lower than the results of a survey of copper fungicide residues in Australian vineyards across 11 regions (that didn't include the Granite Belt) and much lower than residues in Europe and South America (Wightwick et al., 2008).

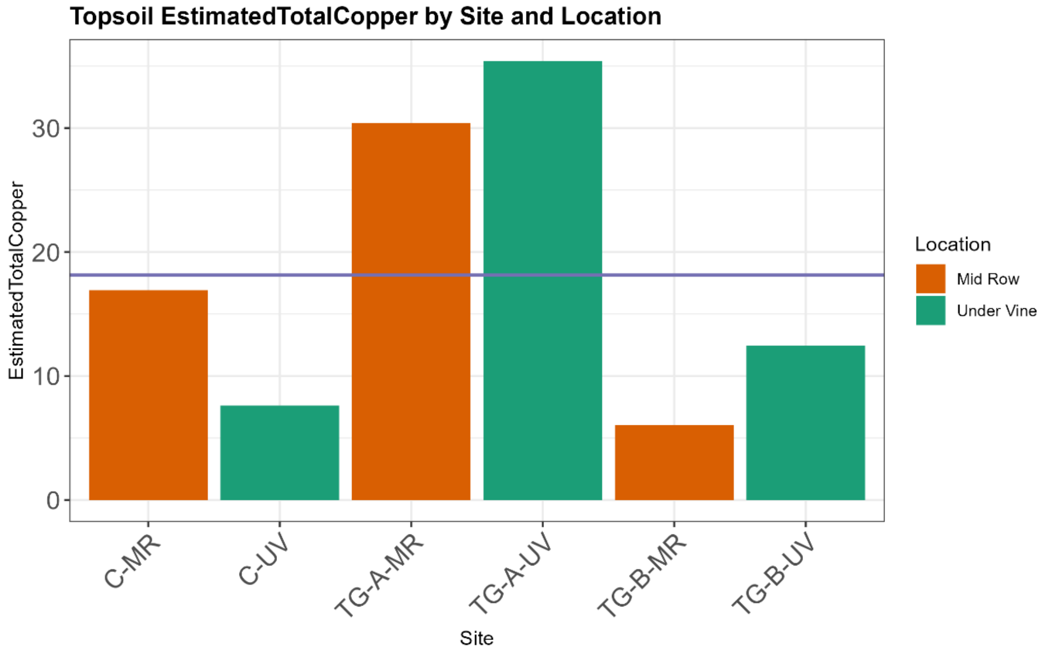

Figure 13 Estimated Total Copper (mg/kg)

The results for sulfur are provided in Figure 14. The levels for the UV are all assessed as high with the MR having much lower, but still in comparison to many soils of the region quite high amounts of sulfur. Sulfur is unlikely to be deficient.

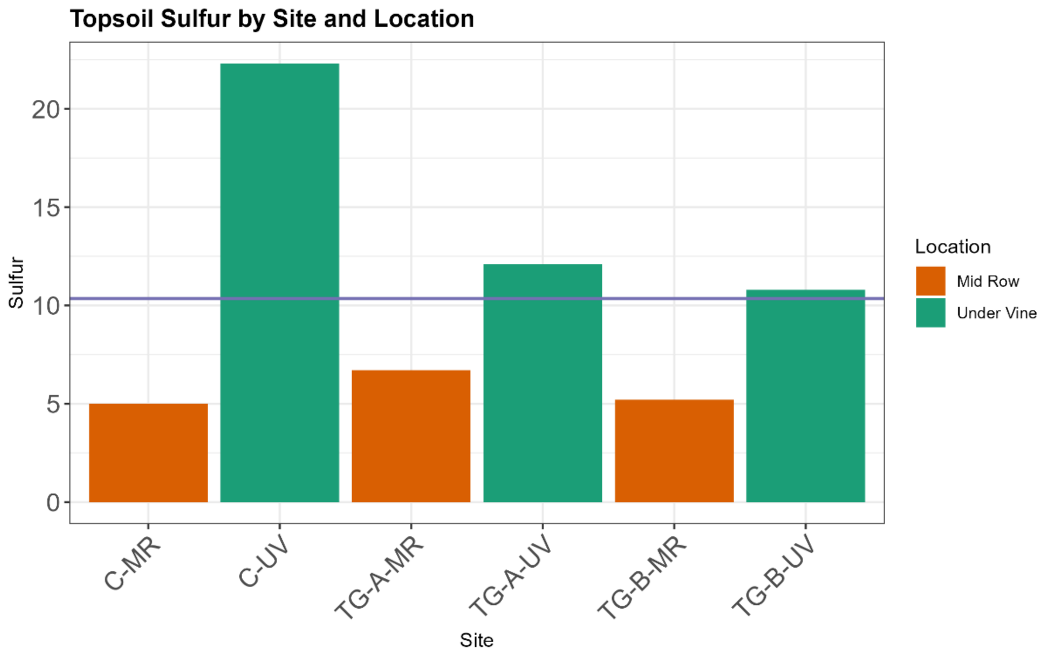

Figure 14 Sulfur (mg/kg) by MR and UV for the three sites. Mean of all results is the horizontal blue line.

3.2.12 Boron

The results for boron are provided in Figure 15. Hassall (2021) report that boron **may** be toxic above 2 mg/kg. The two samples at TG-B have elevated boron compared to the other two sites with the UV sample at 2.3 mg/kg. That both samples at TG-B have elevated levels of boron (and copper) is likely an artefact of previous management practices. The difference between boron levels UV and in the MR maybe associated with differences in SOC. The higher SOC UV may result in more boron being retained whist in the MR boron may be being leached through the soil profile at a more rapid rate explaining the difference.

Vines at TG-B should be monitored for indicators of boron toxicity. Guidance on boron toxicity can be found at (Australian Wine Research Institute, n.d.).

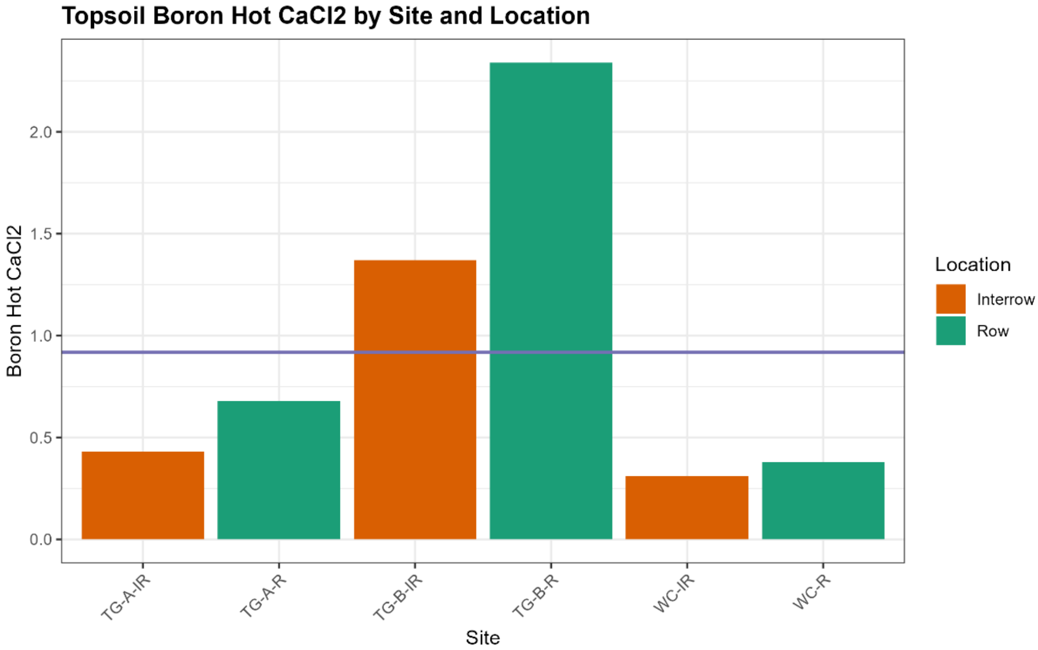

Figure 15 Boron results (mg/kg) by MR and UV for the three sites. Mean of all results is the horizontal blue line.

3.3. Productivity

3.3.1 Yield & quality

There is no readily accessible yield data for vineyards in the Granite Belt region.

TGW report an average yield of 4.9 t/ha over the last six years. Discussions with a small number of viticulturists indicate that this is comparable with other vineyards in the region, suggesting that the TGW system does not incur a yield penalty.

TGW has received multiple awards for its wines, including the best Best Queensland Wine at the Royal Queensland Wine Show for their 2022 Shiraz. An indicator that the viticulture system is producing high quality grapes and wines.

3.3.2 Normalised Difference Vegetation Index (NDVI)

A long term NDVI analysis (from 2017 through to June 2026) of the vineyard block in which the sites were located was completed. Sentinel-2 satellite imagery (resolution 10m, i.e. each pixel was 10 m by 10 m) was accessed via Google Earth Engine over this time. Cloud masking was applied removing images affected by cloud coverage. For each of the over 500 NDVI images available, two NDVI calculations were made.

The first was to determine the 90th percentile NDVI value (NDVI p90) for each pixel. The mean of all the NDVI p90 values was then calculated. This gives an indication of the near peak NDVI values during the most favourable growing conditions/active vine growth. The second was the mean NDVI determined by determining the average NDVI on a per pixel basis, from which the overall mean was calculated. The results are provided in Table 3-5.

Table 3-5 Long Term NDVI Results. Note NDVI values can range from -1 to 1. Higher values represent more active plant growth. Values close to zero represent bare earth and negative values indicate water bodies.

Site	TG-A	TG-B	Control
p90 NDVI	0.63	0.59	0.57
Mean NDVI	0.43	0.44	0.43

The highest mean NDVI p90 value was at TG-A (~7% greater than TG-B and ~10% greater than Control) indicating greater levels of overall photosynthesis during optimal growing conditions. Mean NDVI values across the three sites were the same.

4. Discussion

The purpose of this case study was to provide evidence as to whether low input viticulture is a viable option for wine growers in the Granite Belt through the prism of soil function. The two underlying drivers being optimising water use efficiency and reducing inputs.

The use of the Soil Health Assessment using the EcoVineyards BPMG provided a comprehensive method to compare soil condition between the two sites at Twisted Gum and one site at the Control. This demonstrated both short range variability within a vineyard as well as differences related to management systems between vineyards.

Across the range of soil properties examined, which included soil physical, chemical and biological indicators, soil functionality at Twisted Gum was in almost all instances better than that found at the control.

A summary of the improved soil functionality include:

- The MR topsoil depth was functionally deeper (22 cm and 28 cm vs 11 cm) as observed through soil description and classification.
- Substantially higher organic matter (both UV and in the MR) as evidenced by laboratory results (SOC%, Active Carbon), the TBI as well as the darker colour and ‘feel’ (soil field texture grade) of the soil.

- The higher SOC has increased the ECEC of the topsoil leading to increased capacity to store and exchange cations. The higher SOC can also be expected to improve Anion Exchange Capacity (e.g. for phosphate, sulfate and nitrate) however this was not measured.
- Nitrogen levels equivalent to or higher than the Control without the use of synthetic nitrogen.
- Typically, improved soil structure as evidenced by lower bulk density/higher porosity at TG. This was also observed during soil description where the MR topsoil at both sites had developed some weak soil structure compared to the absence of soil structure (apedal) at the Control.
- Substantially increased capacity to stabilise organic matter inputs under difficult environmental conditions whilst also being capable of rapid decomposition of organic matter under ideal moisture conditions.

The nature of soil as a complex system means that for every action, there can be both positive and negative impacts or reactions. Whilst no major negative impacts from management were identified at Twisted Gum, there were two indicators that are worth considering. They were non-wetting behaviour and minor differences in temperature dynamics.

The non-wetting behaviour is a function of higher levels of SOM and extremely dry conditions. This is a naturally occurring phenomenon that tends to disappear when sufficient moisture is present. It is unlikely to be having any significant impacts but may for example reduce the effectiveness of small rainfall events (e.g. extra moisture maybe lost to evaporation) during prolonged dry conditions.

The soil temperature differences are a corollary of improved soil structure (greater porosity) meaning that soil temperatures are less buffered at TGW than the Control. However, the differences were only minor, and the results need to be considered in the context of several confounding factors which may have influenced the results.

Both of the sites have been managed for intensive horticulture over many decades. Thus, current soil functionality is also linked to historical management practices. An example being elevated levels of copper (although much lower than in the majority of Australian wine growing regions) and elevated levels of boron at one of the TGW sites.

Whilst the overall results indicate a higher level of soil functionality at TGW compared to the Control, the small number of samples collected, and sites assessed imply that the results are observational rather than statistically robust.

Soil function is important, however ultimately the yield and/or quality of the grapes produced in a low-input system must be sufficient to enable a viable business. Estimates comparing the yield from TGW with other local vineyards indicate that TGW is not incurring a yield penalty whilst its receipt of several awards attest to quality. Whilst the results from the NDVI time series analysis indicate mean values lower at both TGW sites than the control, in light of reported yields and quality, this is suggestive of higher water use efficiency of the TGW vineyard.

The results highlight the potential for low input viticulture systems to improve soil functionality in Granite Belt vineyards whilst producing comparable yields and quality grapes. Importantly, these findings were observed during one of the driest periods on record in the Granite Belt, demonstrating the potential for low input systems to build resilience whilst maintaining productive vineyard enterprises under dry conditions.

5. Appendices

1. EcoVineyards BPMG Soil Health Assessment

2. CSBP Soil Laboratory Results

6. References

AUSTRALIAN WINE RESEARCH INSTITUTE n.d. viti-notes: Trace Elements. Glenside SA: Australian Wine Research Institute.

CHÉRON-BESSOU, C., BEILLOUIN, D., THOUMAZEAU, A., CHAPUIS-LARDY, L., CHEVALLIER, T., DEMENOIS, J. & NELSON, P. N. 2025. A global database on land use and management change effects on soil KMnO4-oxidisable organic carbon (POXC). *Scientific Data,* 12**,** 1697.

CHRISTY, I., MOORE, A., MYROLD, D. & KLEBER, M. 2023. A mechanistic inquiry into the applicability of permanganate oxidizable carbon as a soil health indicator. *Soil Science Society of America Journal,* 87**,** 1083-1095.

GONZALEZ-MALDONADO, N., STEENWERTH, K., NOCCO, M. A., YAO, E. H., ZARAGOZA, L. R., MOONILALL, N. I. & LAZCANO, C. 2026. What Is a Healthy Soil for Winegrape Production? Grower Perspectives Differ From Soil Health Paradigms. *European Journal of Soil Science,* 77**,** e70265.

HASSALL, T. 2021. *Winegrape Growing In the Granite Belt: A Practical Guide,* Stanthorpe Queensland, Tony Hassall.

ISBELL, R. & NATIONAL COMMITTEE ON SOIL AND TERRAIN 2021. *The Australian Soil Classification,* Canberra ACT, CSIRO Publishing.

KEUSKAMP, J. A., DINGEMANS, B. J., LEHTINEN, T., SARNEEL, J. M. & HEFTING, M. M. 2013. Tea Bag Index: a novel approach to collect uniform decomposition data across ecosystems. *Methods in Ecology and Evolution,* 4**,** 1070-1075.

MAHER, J. 1996. Understanding and Managing Soils in the Stanthorpe-Rosenthal Region. Brisbane, Queensland: Department of Natural Resources DNRQ96001.

NATIONAL COMMITTEE ON SOIL AND TERRAIN 2024. *Australian Soil and Land Survey Field Handbook,* Canberra, CSIRO.

RAYMENT, G. & LYONS, D. 2011. *Soil Chemical Methods - Australasia,* Collingwood, Victoria, CSIRO Publishing.

RICHES, D., PORTER, I., OLIVER, D., BRAMLEY, R., RAWNSLEY, B., EDWARDS, J. & WHITE, R. E. 2013. Soil biological properties as indicators of soil quality in A ustralian viticulture. *Australian Journal of Grape and Wine Research,* 19**,** 311-323.

ROMIĆ, M., MATIJEVIĆ, L., BAKIĆ, H. & ROMIĆ, D. 2014. Copper accumulation in vineyard soils: distribution, fractionation and bioavailability assessment. *Environmental risk assessment of soil contamination.* IntechOpen.

SCHAPEL, A. & RETALLACK, M. 2024. EcoVineyards best practice management guide on soil health in Australian vineyards: Part A (chemical and physical). Crafters West, South Australia: Retallack Viticulture Pty Ltd.

WIGHTWICK, A. M., MOLLAH, M. R., PARTINGTON, D. L. & ALLINSON, G. 2008. Copper fungicide residues in Australian vineyard soils. *Journal of Agricultural and Food Chemistry,* 56**,** 2457-2464.