



## Developing a tool to assess soil carbon sequestration potential in the Northern Australian rangelands

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### Abstract

We conducted a large research project to address knowledge gaps relating to how grazing management may affect soil organic carbon (SOC) in the northern Australian rangelands. 2257 soil cores over 908 sites were sampled to a depth of 120 cm, and SOC and other relevant soil parameters were determined at 5 cm intervals using spectroscopy. Additionally, in-situ information on land type, land condition and time-series observations of total biomass, vegetation cover, surface reflectance were collected from satellite sensors. The results showed a positive correlation between SOC and land condition. We integrated these results in a modelling tool which will allow us to identify the greatest opportunities for SOC sequestration in the rangelands and potential scenarios of improved grazing management.

### Introduction

Increasing Soil Organic Carbon (SOC) by improving grazing management is being rapidly adopted by the livestock sector as an option for improving soil health and offsetting greenhouse gas emissions. The feasibility of significantly increasing SOC through improved grazing management in semi-arid regions remains less evident (Henry et al 2024, McDonald et al 2023, Bartley 2023). Changes in SOC often occur slowly over long periods, requiring resource intensive long-term monitoring to detect significant trends. Our goal is to develop a tool which integrates soil and vegetation sampling, remote sensing data and modelling to assess the dynamics of SOC in the rangelands. A critical step is to understand and account for the long-term effects of management (especially grazing) and SOC. We used an indirect way to account for grazing management: we assessed Land Condition (LC) and assumed that sites with the same land type (i.e. geomorphology and vegetation) but contrasting LC have had differences in grazing management in recent years. The underlying hypothesis that we tested is that sites with better LC will have higher SOC.

### Methods

We sampled soil properties, vegetation type, LC and historical land management across the Australian Agricultural Company (AACo) cattle stations in the northern rangelands. We sampled the variability in land types using land mapping from Queensland and the Northern Territory. We also used a land type classification generated in house using digital soils mapping techniques (e.g. Minasny 2015), combining data inputs from the Landsat sensor

including fractional and persistent green cover (JRSRP, 2022), and the Radiometric Grid of Australia (Wilford, 2019). We also identified locations with the same land type but contrasting LC scores across a fence. Additionally, we selected 15 paired sites either side of the fence between the cattle grazed Brunette Station and the Connells Lagoon Conservation reserve, which has been intentionally left unburnt and ungrazed since 1982 (Australian Heritage Database, accessed Dec 2024).

### Soil sampling

Soil samples were taken to a depth of 120 cm. Five cores, 10 m apart linearly, were sampled per site in 2022. This was reduced to 3 in 2023 following analysis of the 2022 data (Figure 1). The cores were kept refrigerated at 5°C and transported to a laboratory where they were analysed using the SCANS system (Viscarra Rossel et al 2017). Soil and SOC mass for each 5cm sublayer in each core were calculated following DCCEEW (2024) for spectral modelling. Carbon mass was reported on specified soil masses rather than depth to avoid inaccuracies due to core compression, core recovery and changing bulk density in swelling clays. Results are reported for 3500 and 7000 t soil/ha. These masses represent sampling depths of approximately 30 and 56 cm.

### Vegetation and Land Condition

Land condition (LC) is a relative measure of the health of grazing lands and is determined by simultaneously assessing indicators of soil and pasture condition, woodland thickening and the presence of weeds (Future Beef, accessed Dec 2024). Rangeland officers with experience in the AACo grazing lands performed a rapid visual assessment in each sampling site following the specific regional guidelines published by the Northern Territory or Queensland. To account for conditions which were intermediate between the four ABCD classes, the officers rated each site using a 7-class system including: A, A-B, B, B-C, C, C-D and D.

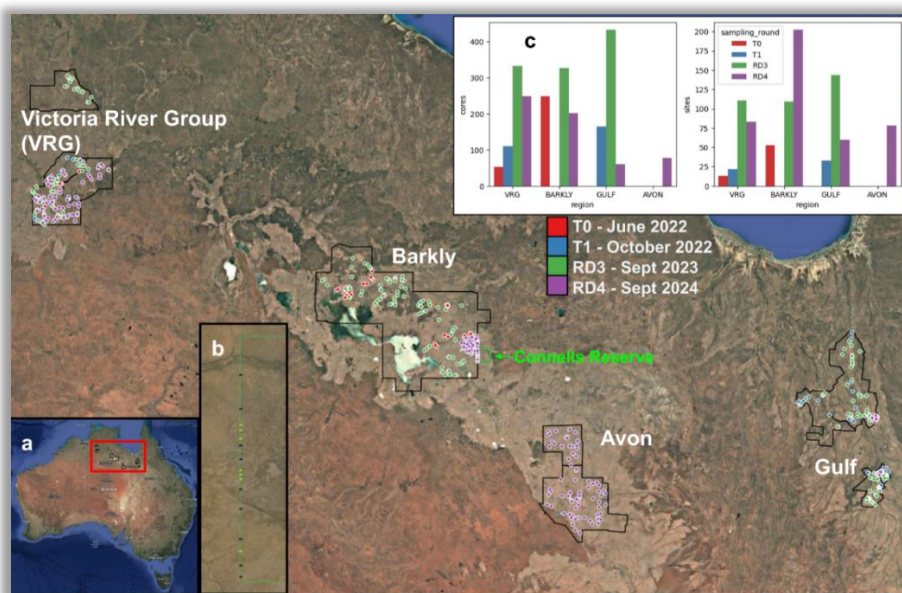


Figure 1: Location of the soil samples collected. Symbol colours correspond to the sampling round as: T0: May/June 2022, (5 cores per site); T1: September 2022, (5 cores per site); RD3: September 2023 (3 cores per site) and RD4: September 2024 (1 core per site). Inset a shows the location of the study area in Australia. Inset b shows the paired sites across the fence dividing Brunette Station (left) from the Connells Conservation Reserve (right). Black and green dots correspond to the clays and rises respectively. Inset c shows the number of cores (left) and the number of sites (right) per region and sampling round.

### Landscape carbon model

The landscape carbon tool integrates a series of models with spatial data and spatially referenced databases for model parameters and management events. The key integrated models include a simple pasture growth model, which is coupled with an implementation of the RothC soil carbon model for Australian conditions (Janik et al., 2002, Skjemstad et al., 2004). LC can be incorporated as either a direct multiplier that affects pasture productivity (Net-Primary Productivity) or as a modifier of the soil cover setting in Roth-C. The final calibration of the integrated model is currently in progress utilising the extensive empirical dataset collected through this project. The initialisation of the SOC pools in RothC is taken from soil carbon baseline mapping, for which we employed a multi-layer perceptron (MLP) model (LeCun et al 2015), trained using soil sampling data collected in the project. Inert Organic Carbon could not be directly measured and was therefore estimated based upon the Soil and Landscape Grid of Australia (SLGA) (Wadoux et al 2022) data. The clay fraction is also determined from the trained MLP model outputs for the AACo estate. Where this more specific data is not available, the model can be run using SLGA data.

### Results

We collected 2257 soil cores over 908 sites between June 2022 and September 2024 (Figure 1). Of these, 450 cores from 150 sites were taken at locations where Land Condition varied across a fence (75 pairs) and 30 cores (15 pairs) corresponded to paired sites in the Brunette Station – Connells Reserve.

### Soil Organic Carbon and Land Condition

SOC mass was positively correlated with Land Condition (a), but the low Pearson's correlation (0.162) indicated that many other factors also determine SOC. Nevertheless, the low p-value from linear regression analysis showed a very low p value, indicating that the probability of finding these results if LC and SOC were not correlated are extremely low. The slope of the regression (1.95) suggests that by every point of improvement in LC (e.g. from C to B condition) results in an average increase in SOC of 0.65 ton C per ha. The 75 paired sites with contrasting LC had a mean difference of SOC of 0.25 ton C/ha (t-test p= 0.11) (b). SOC was, on average, 1.49 ton C/ha higher in the Connells Conservation Reserve (ungrazed) than in Brunette Station (grazed) (c) (t-test p= 0.015). The difference between the grazed and ungrazed SOC was much higher in the rises (mean = 2.53 ton C/ha) than in the clays (mean = 0.58 ton C/ha).

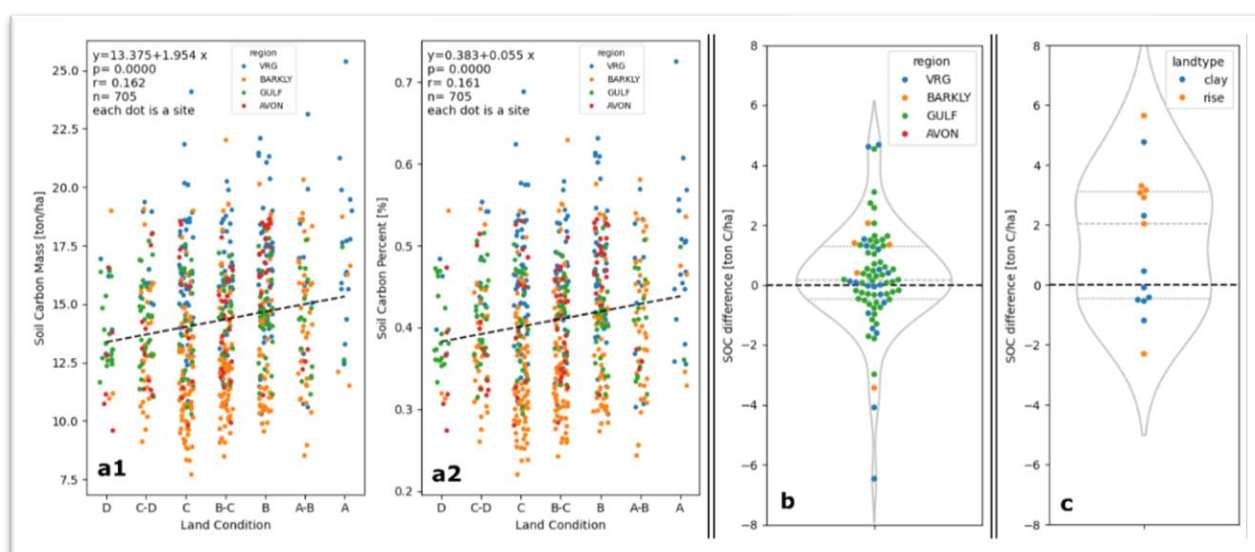


Figure 2: Soil Organic Carbon (SOC) and Land Condition (LC). Panels a1 and a2 show the relationship between SOC and LC over all sites in the study. The black dotted lines show the linear regression between SOC mass (a1) and SOC percent (a2) and LC, where LC was given an ordinal value ranging from 0 (D) to 1 (A). Panel b shows

a swarm plot and violin plot of the difference in SOC mass in the paired sites (n=75). The difference was calculated always as the mass on the better LC side minus the SOC mass in the worse LC side of the fence.

Panel c shows the difference in SOC mass for each paired site between the Connells Conservation Area (ungrazed) and the Brunette Station (grazed).

### ***Soil Organic Carbon Baseline and Landscape Carbon modelling***

Figure 3a shows the baseline SOC map of the study area. Figure 3b shows an example simulation based on preliminary model calibration. The simulation incorporates the time-series climate data, together with site specific soil properties. Two scenarios were simulated: business as usual, and an improved Land Condition. Both scenarios have the same historical data and assumptions, with the improved Land Condition, scenario only differing from 2025 with an assumed uplift in Land Condition. The interannual variation due to climatic variability, influencing both pasture growth and soil carbon decomposition, is obvious. As the scenarios move into a projection from 2025, both scenarios show the same underlying variability due to the cycled climate data, with a gradual build in the soil carbon mass for the improved Land Condition over the 20-year projection period compared to the business-as-usual scenario.

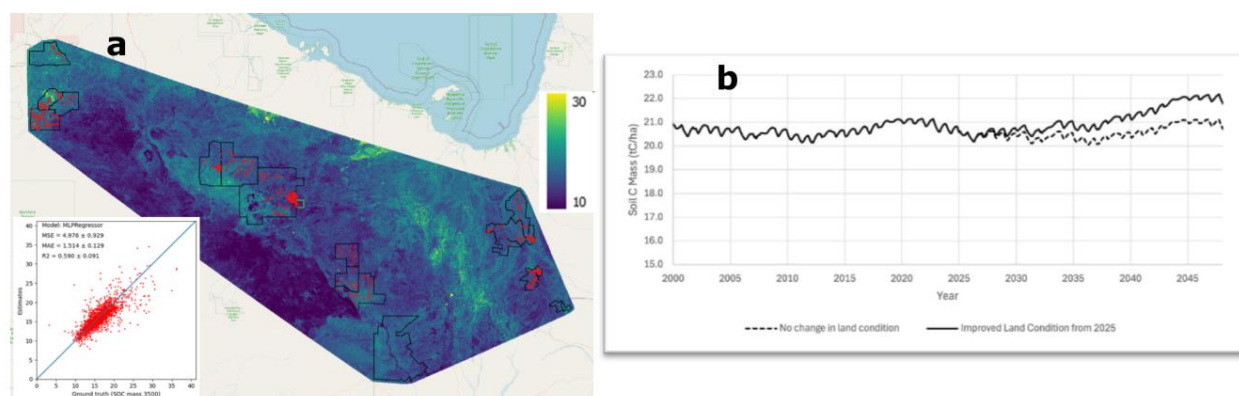


Figure 3: a: Soil Organic Carbon Baseline showing the SOC mass in the top 3500 tons of soil in ton SOC per ha. The red dots show the soil sampling locations. The inset scatterplots show the relationship between the measured SOC and the SOC value from the baseline. b) Example SOC Mass for top 3500t soil mass, historical trend, and projected scenarios from 2025 for a ‘No change in Land Condition’ and an ‘Improved Land Condition scenario’

### **Discussion**

With these comprehensive data we assessed the relationship between SOC and land management in 3 ways. In two of these we used Land Condition as a proxy for grazing management effects on the vegetation and soils with a space-for-time method. We found a noisy but positive and statistically significant relationship between LC and SOC. On average, the difference due to one LC class (e.g. class C vs B) resulted in a difference of 0.65 ton C per ha. When we compared contrasting LC states across a short distance over a cattle fence, however, the differences we found were more modest (0.25 ton C/ha higher on the better LC side). We speculate that LC is indeed a useful indicator of SOC in Australia’s northern grazing land, and the experiments of Bray et al (2014) did not have the statistical power to find such results due to a more limited sampling size. As in all space-for-time methods we need to be cautious about the potential pitfalls of the approach. First, the correlation between SOC and LC does not conclusively prove a causal link. Second, these findings do not answer the question: if land condition is improved, how long it will take to see increases in SOC? Other studies suggest that in arid lands this could take at least 5 to 20 years (Bartley et al 2023). Our preliminary simulation results using the integrated model support this, with climatic variability remaining an important driver, with a gradual modest long-term increase in SOC. The results found in the Connells Reserve / Brunette Station fence further support the causal connection, and positive response of SOC to management change. There, the difference in SOC between the excluded and the grazed areas was on average 1.5 ton C/ha. We speculate that the increase in SOC under a better grazing strategy could potentially be even higher (Stanley et al 2024). Even though this study provides the most extensive sampling, and convincing

evidence of the potential for SOC sequestration in the Northern Australian Rangelands, the establishment of long-term grazing trials would be invaluable. Using these results we produced a SOC baseline for the wider area under study and a process-based model that allows to simulate Carbon stocks and fluxes over time. Our tool is being refined and will enable us to accurately and affordably estimate soil and vegetation carbon in Australian rangelands.

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