Analysis of soil tests for Soil Carbon Benchmarking Project

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19 June 2023

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Contents

Summary

Soil samples to a depth of 30 cm were collected from four paddock sites on ten farms near Busselton, Manjimup and Donnybrook. The purpose was to provide a benchmark of soil carbon stocks for different soil types, and to investigate any associations with other variables that may explain differences in soil carbon between sites.

There were no clear relationships between soil carbon and other measured variables, which makes it impossible to make any specific recommendations from these data, but the results did provide useful insights.

- The levels of soil carbon of the 40 paddock sites sampled in this project were generally at the upper end of values expected for the south-west region of Western Australia.
- The data provide measurements of soil organic carbon and calculated carbon content that are a basis for monitoring in future years. Continued sampling will enable assessment of any changes in soil carbon in response to seasons, production or management.
- The project was established as a pilot with a small number of sites across a range of soil types and geography. As such the data form a starting point for a structured survey and monitoring and are a useful set for comparison with other sites, paddocks and farms.
- There was variability between paddock sites across the same farm and between the farms. This suggests that there could be potential for some, likely small, accumulation of soil carbon, particularly in the subsoil.
- Practical recommendations from researchers in the field to increase soil organic carbon are to overcome soil constraints and to increase the duration of vegetation covering the soil. Management and agronomic practices to achieve these objectives are likely to benefit productivity.

Introduction

South West NRM worked with ten livestock producers located near Busselton, Manjimup and Donnybrook to collect soil samples for analysis of soil organic carbon and other variables (Figure 1). They sampled a total of 40 sites (four paddock sites on each farm) with samples at each site taken from 0–10 cm, 10–20 cm and 20–30 cm using National Soil Carbon Research Program (SCaRP) field methodologies (Sanderman et al 2016).

The sites were selected by the participating farmers and were chosen to provide a contrast between aspects such as poor and good production, different soil types and/or different position in the landscape. They were not intended to be a representation of the farm, nor of the broader landscape, but it was hoped that they would provide a range of soil carbon levels. Full details of the sampling, processing and analysis of the samples is provided in the Appendix.

The carbon content for each soil depth was calculated using the results from the laboratory analyses and from South-West NRM (total soil organic carbon and bulk density, adjusted for the proportion of gravel, if any). This report presents a summary of data from the 120 soil samples and an exploration of potential relationships of soil organic carbon and calculated carbon content with possible influencing variables.

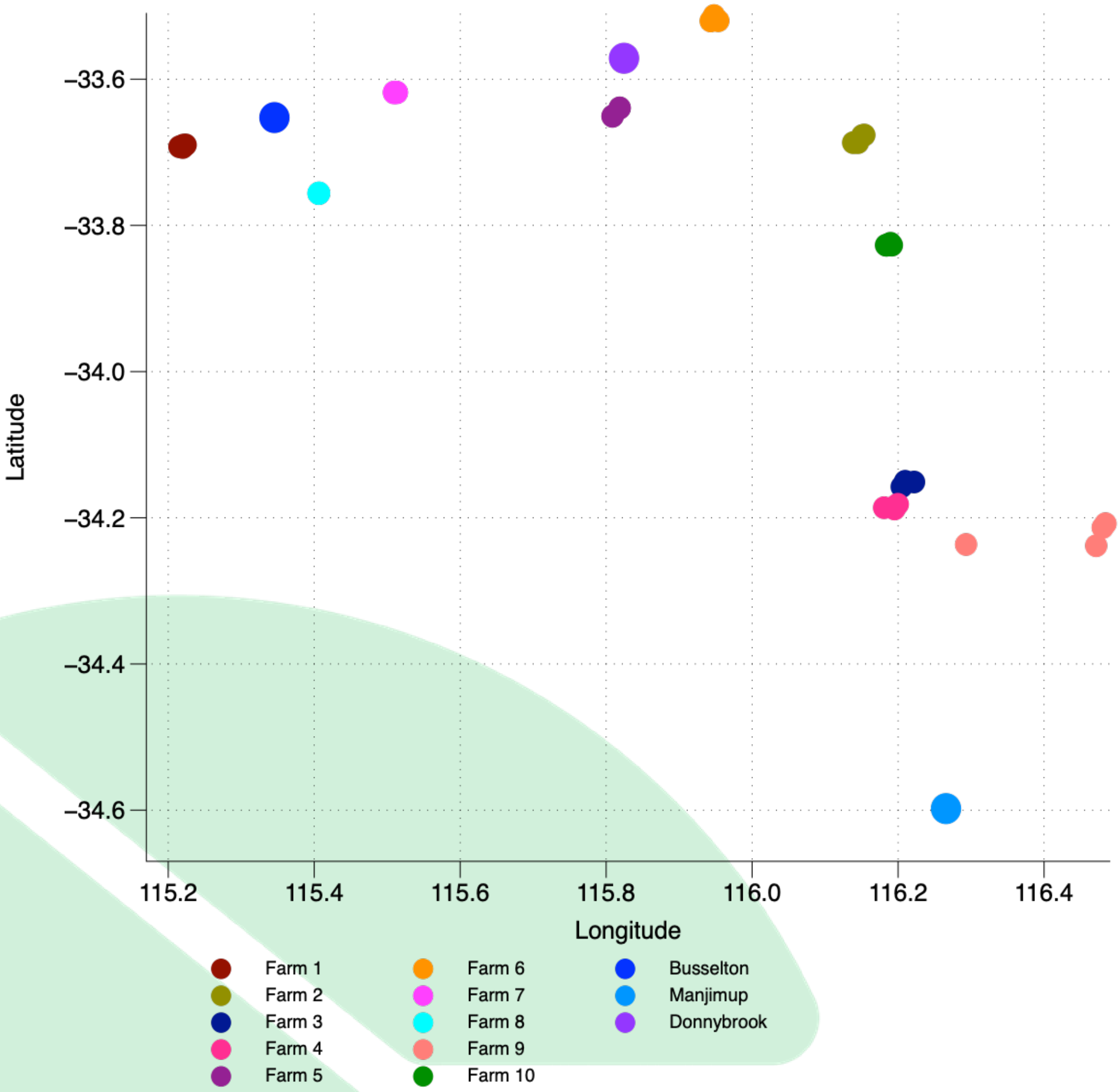

Figure 1. The spatial distribution of the sites by longitude and latitude, colour-coded by farm. The locations of Busselton, Manjimup and Donnybrook are shown for reference.

Results

The texture of the 120 samples ranged from sand to clay loam (Table 1). The majority of the samples were in the sand to loam range and these texture classes were distributed fairly evenly across the depths. The soil profiles ranged from sand at all depths to loam at all depths. The two most common profiles were loamy sand or loam at each depth (8/40 profiles each), followed by sand at each depth (7/40 profiles), sandy loam at each depth (3/40 profiles) and a loamy sand topsoil over sand at depth (2/40) profiles. The remaining 13 profiles were individual mixes of differing textures at each depth.

Table 1. The number of samples at each depth in each texture class.

Depth	Sand	Loamy sand	Sandy loam	Loam	Clay loam
0–10	7	15	8	10	0
10–20	9	11	8	12	0
20–30	11	10	8	9	2

Total organic carbon across all depths ranged from 0.1 to 22.1% and the calculated carbon content from 1.50 to 106.4 t/ha, with an average content of 39.2 t/ha. The highest soil organic carbon and calculated carbon content was in the topsoil (Table 2). This was as expected, but the measured soil organic carbon was at the upper end of expectations. Nearly half of the topsoil measurements (19 out of 40) were above 6%, most of these were between 6.02–8.61%, with the two highest being 13.8 and 22.1% (associated with peat soil). The maximum soil organic carbon measured in this area in a previous survey was 8.2% (F. Hoyle, pers. comm.), so many of the sites in this study are at the upper end of soil organic carbon for this environment.

Table 2. Average soil organic carbon (OC%) and calculated carbon content (t/ha) according to the depth of sampling. Walkley and Black (W&B) and total OC are provided for comparison. Four samples taken from 0–20 cm and 10–30 cm depths were excluded from the calculation of the average values (Appendix).

Depth (cm)	OC W & B (%)	Total OC (%)	C content (t/ha)
0-10	6.5	6.0	62.0
10-20	2.9	2.6	34.5
20-30	1.7	1.4	21.0

When aggregated across all depths, the average calculated carbon content was lower for soil samples with a sandy texture than those classed as loam, loamy sand or sandy loam (data not shown), but there was no difference within the three depths (Figure 2).

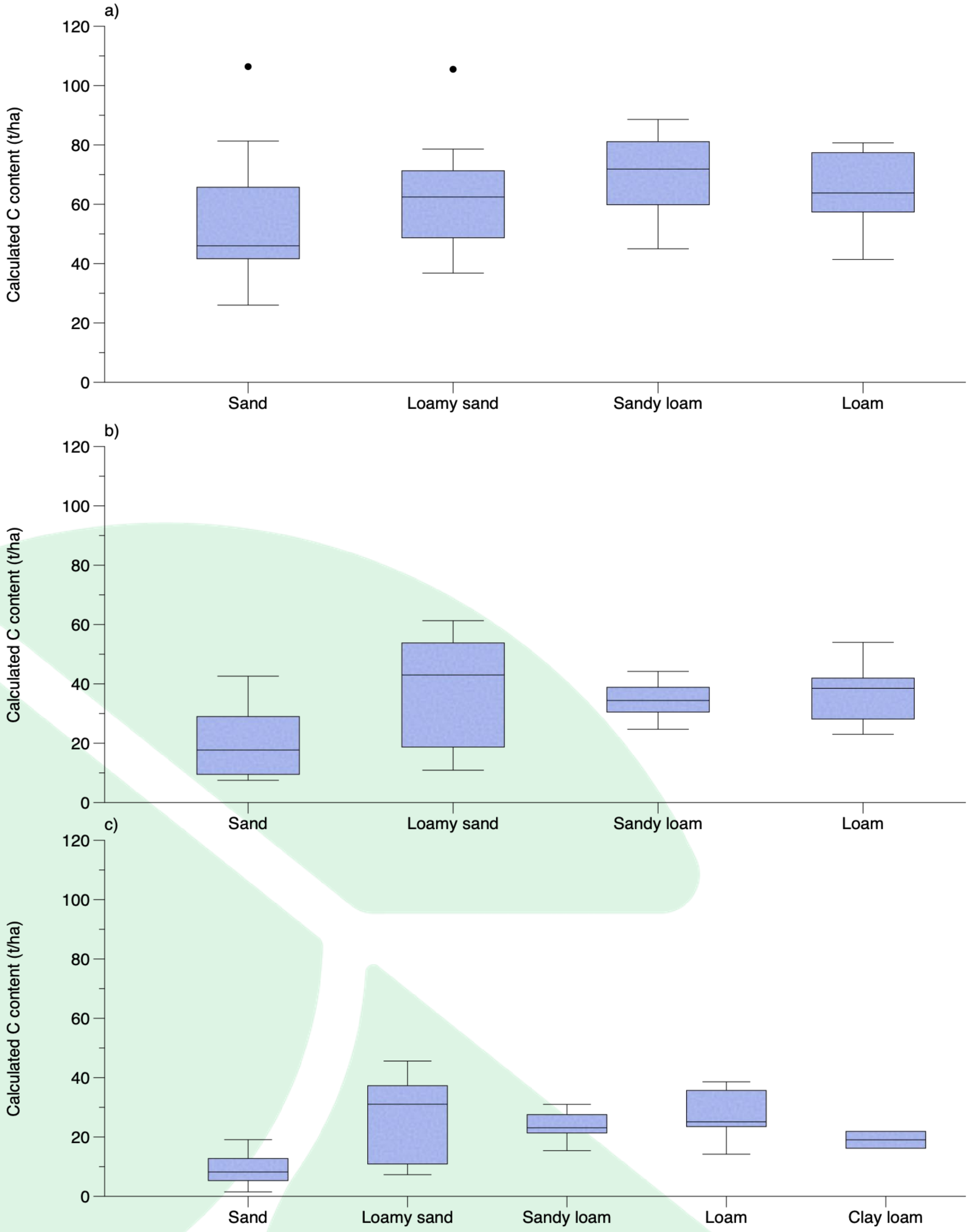

Figure 2. Range of calculated carbon content (t/ha) for all samples according to soil texture for a) 0–10 cm, b) 10–20 cm and c) 20–30 cm. The box is bounded by the upper and lower quartile (75% and 25% of samples below each value respectively). The line within the box is the median. The upper and lower whiskers represent the maximum and minimum values respectively, except in the case of outliers, which are shown as separate points, with the upper whisker the same magnitude as the lower.

The distribution of the calculated carbon content did not differ according to the average annual rainfall of the nearest Bureau of Meteorology site to each farm (Figure 3). The spread of calculated carbon content with soil texture was similar within each average annual rainfall grouping (data not shown). Similarly, there was no relationship between the calculated carbon content and the clay content of the soil (Figure 4), nor the pH (Figure 5) nor any of the macro nutrients (N, P, K and S), nor EC as an indicator of salinity (data not shown).

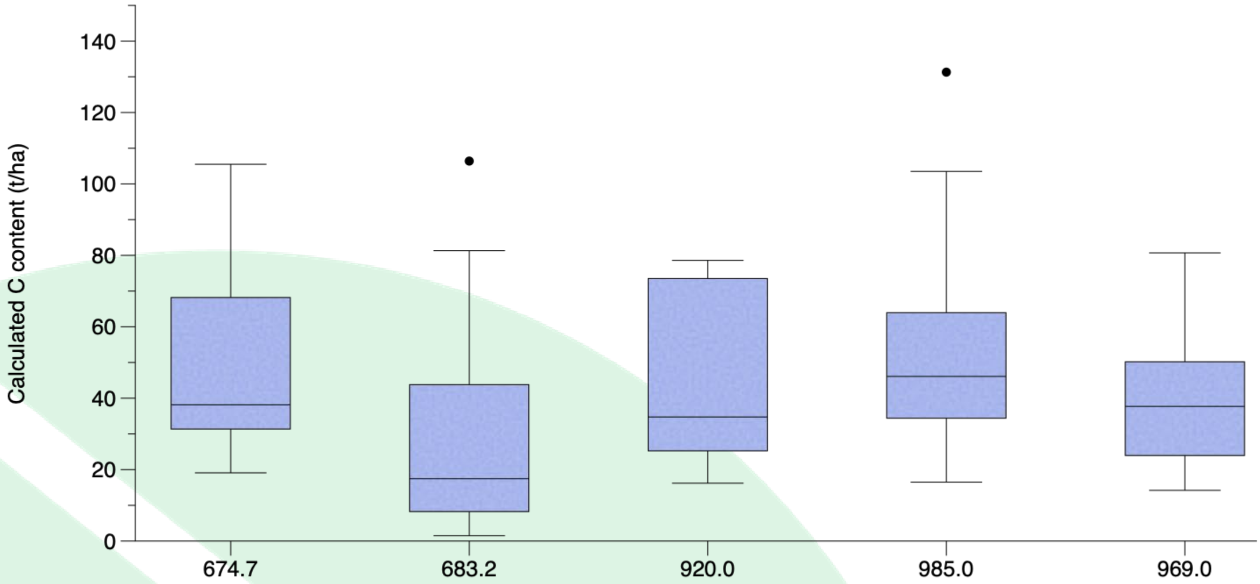

Figure 3. The distribution of calculated carbon content (t/ha) with the average annual rainfall of the nearest Bureau of Meteorology site to each farm.

There was a weak relationship between the total organic carbon and the bulk density of the soil ($R^2 = 0.55$, Figure 6). The regression coefficients were highest for the 0–10 cm and 10–20 cm depths if only the sand and loamy sand were included ($R^2 = 0.59$ and 0.42 respectively). A slight tendency for the total organic carbon to be lower for the samples of the same texture with higher bulk density provides weak, indirect evidence that compaction may be an influencing factor on the soil carbon.

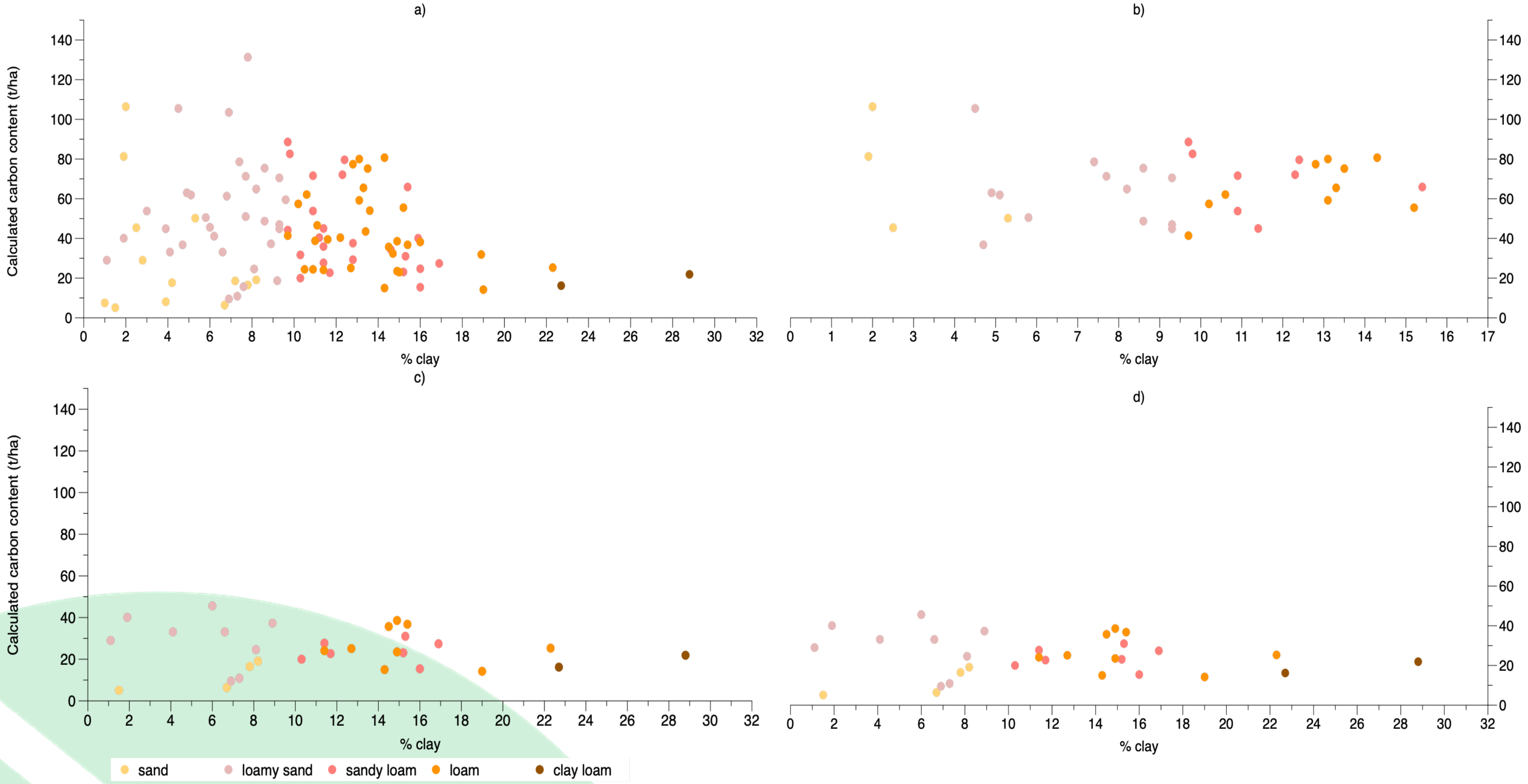

Figure 4. The distribution of calculated carbon content (t/ha) with clay content of the soil sample for a) all depths, b) 0–10 cm, c) 10–20 cm and d) 20–30 cm. Points are colour-coded by soil texture.

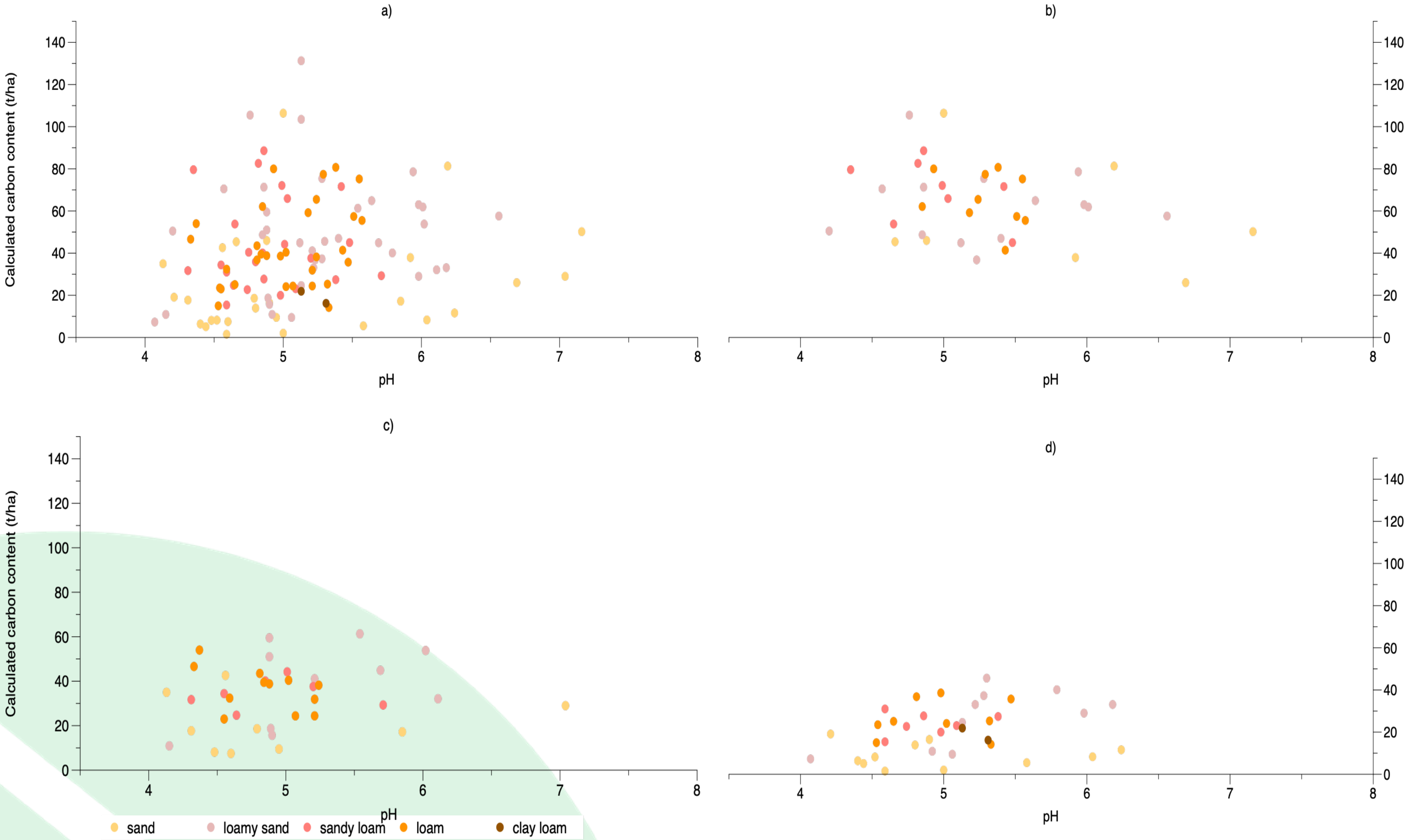

Figure 5. The distribution of calculated carbon content (t/ha) with pHCaCl of the soil sample for a) all depths, b) 0–10 cm, c) 10–20 cm and d) 20–30 cm. Points are colour-coded by soil texture.

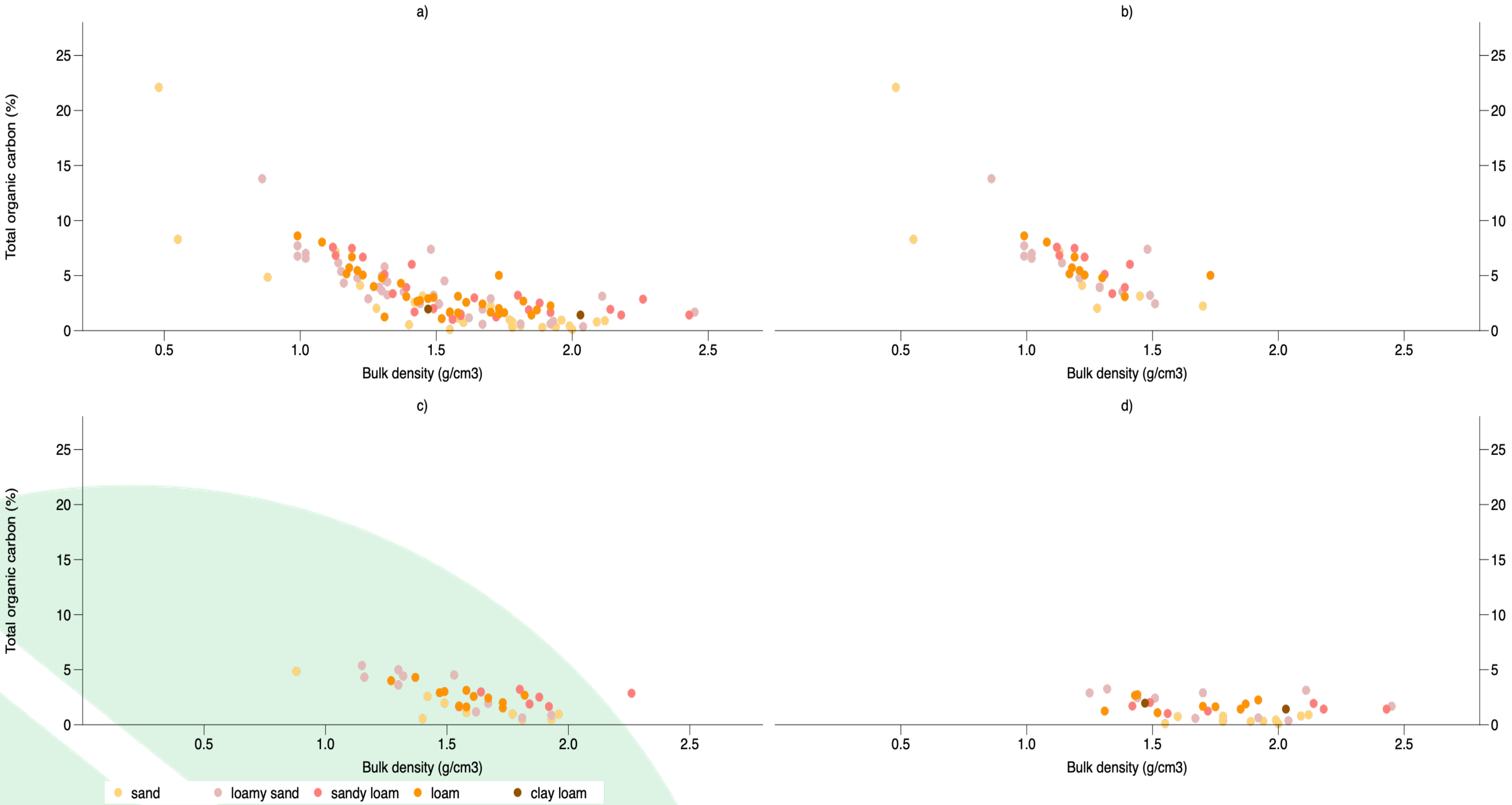

Figure 6. The distribution of total organic carbon (%) with the bulk density of the soil sample for a) all depths, b) 0–10 cm, c) 10–20 cm and d) 20–30 cm. Points are colour-coded by soil texture.

There was variability between the farms in the carbon content at each soil depth, but relative consistency between the paddocks within a farm (Figure 7). The greatest differences in content were in the topsoil, but there is a mathematical influence to this since this depth had the largest magnitude of values compared to the deeper layers. The widest range of values for the carbon content of the topsoil were for farms 2, 5 and 8. In general, the sites were selected by the farmers to try to provide a range of results.

The characteristics of the lowest and highest ranked sites at each depth for the four main soil textures in the dataset do not indicate any consistent influences (Table 3). This is to be expected given that these are merely a subset of the overall data and so exhibit the same lack of relationships as the full dataset.

The RothC model (Rothamsted Research 2014) was used to produce estimates of the change in soil carbon for each paddock over 100 years. The model was run using weather data from the nearest available Bureau of Meterology or Department of Primary Industries and Regional Development site and theoretical pasture production following the schema of Hoyle et al (2013). The estimates projected a small decrease in carbon content over 100 years for 39 of the 40 paddocks (by 10–40 t/ha, or 0.1–0.4 t/ha.year). The remaining paddock, which had the lowest calculated carbon content in this dataset, was projected to increase slightly over 100 years (by 8 t/ha, or 0.08 t/ha.year).

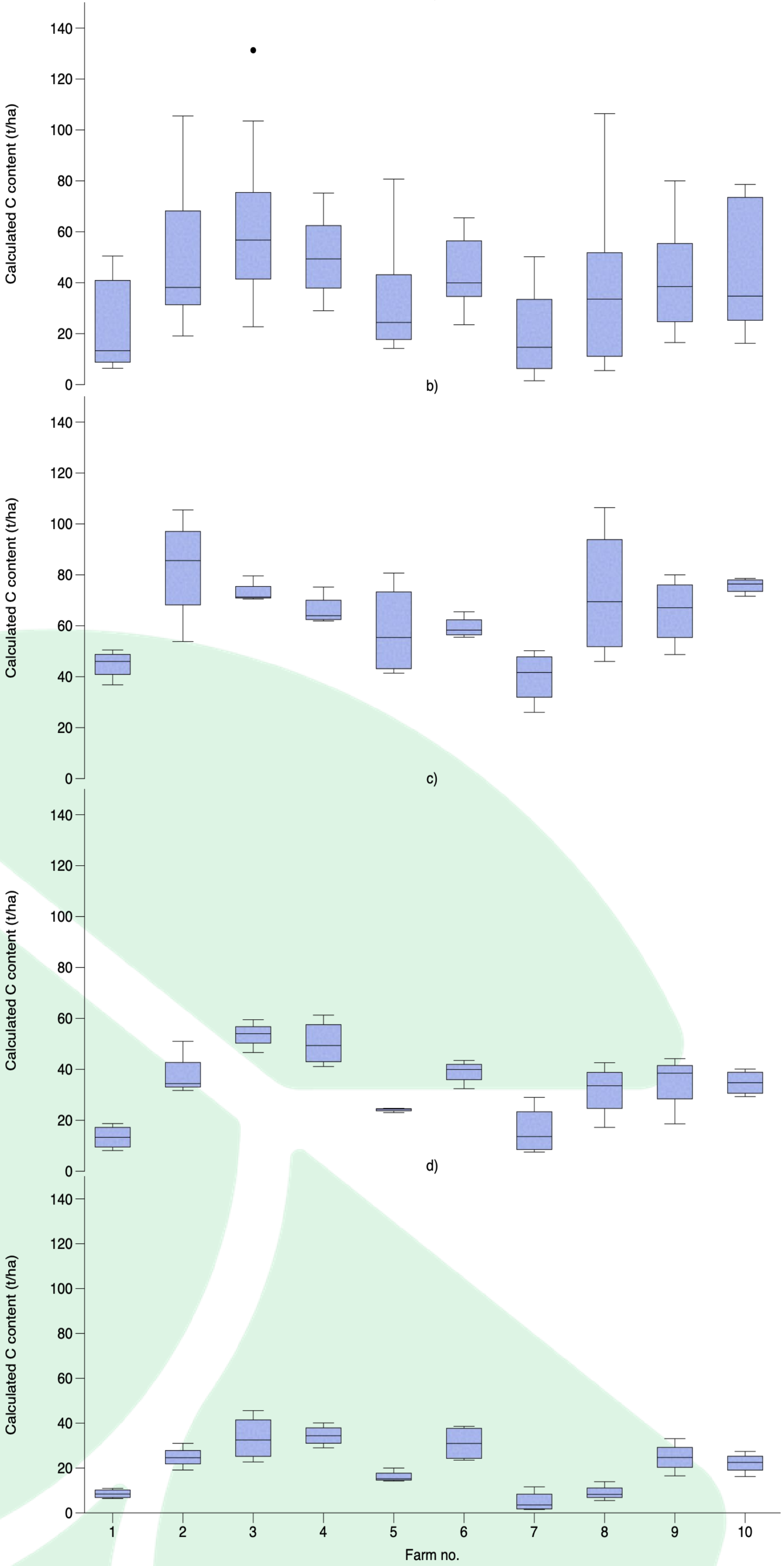

Figure 7. The distribution of calculated carbon content (t/ha) for each of the ten farms for a) all depths, b) 0–10 cm, c) 10–20 cm and d) 20–30 cm.

Table 3. Characteristics of the lowest and highest ranked sites for the four main soil textures at each depth. Sites coded by farm (Fm) and paddock (Pdk) number.

Texture	Depth	Rank	Fm	Pdk	C (t/ha)	Rain (mm)	Clay (%)	Bulk density (g/cm³)	pH	EC dS/m	Comments
Sand	0–10	7/7	7	26	26	683	<1	1.28	6.69	0.19	previously bluegum considered better half of paddock
		1/7	8	29	106.4	683	2	0.48	5	0.59	dairy, annual pasture-seeded each year, rotational grazing
	10–20	9/9	7	26	7.5	683	1	1.40	4.6	0.03	previously bluegum considered better half of paddock
		1/9	8	31	42.6	683	<1	0.88	4.56	0.18	dairy, annual pasture-seeded each year, rotational grazing
	20–30	11/11	7	26	1.5	683	<1	1.55	4.59	0.025	previously bluegum considered better half of paddock
		1/11	2	7	19.1	675	8.2	2.12	4.21	0.017	lowest rain of sampled farms, other depths sandy loam, some rotational grazing
Loamy sand	0–10	14/14	1	3	36.8	683	4.7	1.51	5.23	0.13	autumn ‘sacrifice paddock’, loamy sand over sand, hard at depth
		1/14	2	5	105.5	675	4.5	0.86	4.76	0.14	lowest rain of sampled farms, loamy sand at all depths, some rotational grazing
	10–20	10/10	1	4	10.9	683	<1	1.81	4.15	0.14	holding paddock, poorly utilised pasture, never limed, loamy sand at all depths
		1/10	4	15	61.3	985	6.8	1.3	5.54	0.1	high input system, rotational grazing, some perennials, re-seeded each year
	20–30	10/10	1	4	7.3	683	<1	2.04	4.07	0.05	holding paddock, poorly utilised pasture, never limed, loamy sand at all depths
		1/10	3	12	45.6	985	6	2.11	5.3	0.043	considered poor paddock, lower in landscape, much guildford grass, loamy sand at all depths

Texture	Depth	Rank	Fm	Pdk	C (t/ha)	Rain (mm)	Clay (%)	Bulk density (g/cm³)	pH	EC dS/m	Comments
Sandy loam	0–10	8/8	1	1	45	683	11.4	1.34	5.48	0.084	loamy sand at deeper depths, high input paddock, trafficked
		1/8	2	8	88.6	675	9.7	1.19	4.86	0.074	lowest rain of sampled farms, sandy loam throughout, some rotational grazing
	10–20	7/7	5	20	24.7	969	16	1.55	4.64	0.041	more productive paddock, more re-seeding, sandy loam at all depths
		1/7	9	34	44.2	985	9.7	1.8	5.01	0.076	blue gums removed in 2022, still some stumps
	20–30	7/7	5	20	15.4	969	16	1.56	4.59	0.035	more productive paddock, more re-seeding, sandy loam at all depths
		1/7	2	8	31	675	15.3	2.18	4.59	0.022	lowest rain of sampled farms, sandy loam throughout, some rotational grazing
Loam	0–10	10/10	5	18	41.4	969	9.7	1.39	5.43	0.088	hill country, loam over sandy loam at depth
		1/10	5	19	80.7	969	14.3	1.73	5.38	0.089	more productive paddock, more re-seeding, loam at all depths
	10–20	12/12	5	19	23	969	15	1.73	4.55	0.039	more productive paddock, more re-seeding, loam at all depths
		1/12	3	11	54	985	13.6	1.37	4.37	0.063	loam layer with sandy loam topsoil and 20–30 cm
	20–30	9/9	5	17	14.2	969	19	1.52	5.33	0.044	hill country, loamy sand topsoil over loam
		1/9	6	23	38.6	969	14.9	1.92	4.98	0.041	loam at all depths

Conclusions

The data provide useful insights, despite no clear indicators or associations between the measured soil organic carbon or calculated carbon content and any of the expected explanatory variables.

The results for the 40 sites sampled in this project were generally at the upper end of soil carbon levels expected for the south-west region of Western Australia. This may suggest that the soil has achieved an equilibrium state for soil carbon, under current land-use. Given the large temporal and spatial variability associated with measurements of soil carbon, it is preferable to re-sample the paddocks and sites in time. Further sampling and analysis over coming years will help to build a picture of any changes in soil carbon in response to seasons, production or management.

The dataset examined is sizeable, but not extensive. The project was established as a pilot and the range and variation of the paddock sites selected was determined by those who participated. It was not set up as a transect nor to sample a range of paddocks by location, production, morphology, geography or other variable. As such the data represent a starting point and a baseline of soil organic carbon for the four paddocks of the participating farmers and a useful basis of comparison for other sites, paddocks and farms.

The lack of associations between soil carbon and other measured variables makes it impossible to make any specific recommendations from these data. Nevertheless, the variability between paddock sites across the same farm and between the farms, plus the fact that around half of the carbon at each site was present in the 0–10 cm layer, indicate that there could be potential for some, likely small accumulation of soil carbon, particularly in the sub-surface and subsoil layers.

The accumulation of soil organic carbon in biological systems occurs from a seemingly simple balance of inputs and outputs so that increasing soil organic matter is a ‘simple’ matter of having inputs exceed losses (Farrell et al 2021). There are no specific results quantifying changes in soil organic carbon with land-use or farm practices for south-west Western Australia. Meta-analyses of long-term experiments across the world point to variable and likely small increases in soil organic matter in response to changes in practice (e.g. Lessmann et al 2022, FFAO and ITPS 2021, Xu et al 2020). Greater changes have been observed in sub-tropical and tropical environments and from changes that close large gaps in yield and/or reduce large losses of soil organic carbon.

In line with this, the greatest measured changes in soil organic carbon in Mediterranean-type environments have come from significant changes in farm practices, such as from full tillage to no tillage, no fertilisation to use of added fertiliser and full cropping to pasture production and/or cover cropping (Lessmann et al 2022). Changes such as these were implemented in Western Australia during the 1980s and 1990s and are now common practice across Australian agriculture (Sanderman et al 2010, Farrell et al 2021).

In Australia, agronomic recommendations to increase soil organic carbon currently are to overcome soil constraints and to focus on the duration of vegetation covering the soil (Farrell et al 2021). Soil constraints, such as compaction, acidity, water repellence and sodicity, are seen as the greatest barrier to achieving potential production for given rainfall. Increasing the duration of vegetative cover increases the input of organic matter and is more important than diversity of plant species *per se.*, although it is recognised that increasing the diversity of plant species grown can be a means to increase the duration of soil cover across the year. Fortunately, management and agronomic practices to achieve these objectives are likely to benefit productivity.

Compared with agronomic factors, the sequestration of soil carbon is more likely following major interventions such as retiring farmland or incorporating carbon (e.g. manure, compost, biochar) or clay to depth. The retirement of farmland is a response that is not economically viable when compared to productive agriculture, so, under current economic settings, is only likely to be considered for unproductive areas of a farm (on which the growth of plant species to sequester carbon is also restricted). Incorporating carbon or clay to depth are means of increasing soil carbon directly or through physical-biological processes, but they are expensive. Additionally, it has been noted that the “off-site” transfer of organic amendments can result in an increase in carbon sequestration at one farm or site at the expense of reductions at another, thus having little or no impact on the overall balance (Amelung et al. 2020).

The results of the analysis carried out using the RothC model should be interpreted with caution. In brief, the inputs of carbon in the RothC model are determined from the water deficit (calculated from rainfall, temperature and pan evaporation) and input of organic matter based on the biomass produced and clay content of the soil. The RothC model is best used with specific data related to an experiment or monitoring site. As such the analyses would need to be repeated with more site-specific data regarding biomass production, rainfall and evaporation in order to provide greater confidence in the results. The results generated in this analysis at best indicate that there is a low likelihood of changing the soil carbon of these paddocks through agricultural practices.

The sampling and analysis conducted in this pilot project are a starting point for further monitoring by the participating farmers, at the enterprise and paddock level, and at the landscape level by partnering research and government organisations. The absence of structured, long-term monitoring sites in the south-west of Western Australia, a climate and biodiversity ‘hot spot’, represents a yawning gap in monitoring of stocks of soil carbon and research into the quantification of any changes with climate, management and land-use.

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Acknowledgements

This project was delivered by South West NRM for the Landcare Farming Program, a joint partnership between Landcare Australia and the National Landcare Network, funded by the Australian Government's National Landcare Program, and supported by Western Beef Association Inc.

References

Amelung, W, Bossio, D, de Vries, W, Kögel-Knabner, I, Lehmann, J, Amundson, R, Bol, R, Collins, C, Lal, R, Leifeld, J, Minasny, B, Pan, G, Paustian, K, Rumpel, C, Sanderman, J, van Groenigen, JW, Mooney, S, van Wesemael, B, Wander, M and Chabbi, A (2020) Towards a global-scale soil climate mitigation strategy. Nature Communications 11, 5427. https://www.nature.com/articles/s41467-020-18887-7.pdf

FAO and ITPS (2021) Recarbonizing global soils: A technical manual of recommended management practices. Volume 3: Cropland, Grassland, Integrated systems and farming approaches – Practices overview. FAO: Rome. https://doi.org/10.4060/cb6595en

Farrell, M, Gupta, VV and Macdonald, LM (2021) Addressing The Rundown Of Nitrogen And Soil Organic Carbon. In GRDC Research Updates, Adelaide. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2021/02/addressing-the-rundown-of-nitrogen-and-soil-organic-carbon

Hoyle, FC, D'Antuono, M, Overheu, T and Murphy, DV (2013) Capacity for increasing soil organic carbon stocks in dryland agricultural systems. Soil Research 51, 657-667.

Lessmann, M, Ros, GH, Young, MD and de Vries, W (2022) Global variation in soil carbon sequestration potential through improved cropland management. Glob Chang Biol 28, 1162-1177.

Rothamsted Research(2014) Rothamsted carbon model (RothC) https://www.rothamsted.ac.uk/rothamsted-carbon-model-rothc

Sanderman, J, Baldock, JA, Hawke, B, MacDonald, L, Massis-Puccini, A and Szarvas, S (2016) National Soil Carbon Research Programme: Field and Laboratory Methodologies. CSIRO: Urrbrae. https://csiropedia.csiro.au/wp-content/uploads/2016/06/SAF-SCaRP-methods.pdf

Sanderman, J, Farquharson, R and Baldock, JA (2010) Soil carbon sequestration potential: A review for Australian agriculture. 81 pp. CSIRO Sustainable Agriculture Flagship: Adelaide, Australia.

Xu, S, Sheng, C and Tian, C (2020) Changing soil carbon: influencing factors, sequestration strategy and research direction. Carbon Balance and Management 15, 2.

Appendix

Sampling protocol

Each site consisted of a 20 m x 20 m plot. Samples were taken from ten random points within the plot using a stainless steel exhaust pipe with 48 mm internal diameter. Samples were collected for each 10 cm depth at each point and bulked together into one sample per depth per site. The soil was not scuffed, and vegetation was pushed aside before inserting the core.

In some cases, difficulties extracting intact cores meant that fewer than ten cores were extracted (number of cores averaged 9.3 per site). At two sites, difficulties were so extreme that samples could not be collected for two depths. These were from 0–20 cm from one site at Farm 3, and from 10–30 cm from one site on Farm 2.

Samples were kept cool and transported to a lab typically the same day where the total sample was weighed and the number of cores per sample recorded. For each sample, the soil was mixed thoroughly and a 500–700 g subsample taken. This was dried for a minimum of 48 hours at 40°C in an oven.

The samples were sent to a commercial laboratory for analysis. Prior to analysis, the laboratory screened the samples to <2 mm and used an ultra-fine grind to achieve >90% of each sample passing through a 100 µm screen. The laboratory conducted analyses for total organic carbon (TOC - 6B3 method), as well as mid-Infrared particle size analysis (% sand, silt and clay) and a range of other soil properties.

For the remainder of the sample, another 300 g subsample was taken and dried at 105°C to determine moisture content by comparing weights before and after drying. This moisture content was used to determine the dry weight of the entire sample. Bulk density was calculated using this dry weight and the total volume of soil collected (core volume x number of cores taken).

This bulk density was used in the calculation of carbon content (tonnes per hectare) for each 10 cm depth. To account for gravel content, the volumetric gravel content provided by the laboratory was used to deduct the gravel proportion from the initial carbon (t/ha) result for each 10 cm depth.