Soil Carbon in South Australia

Volume 4: Benchmarks and Data Analysis for the Agricultural Zone 1990 - 2007

Amanda Schapel (PIRSA), Tim Herrmann, Susan Sweeney and Craig Liddicoat
Department for Environment and Water
May, 2021

DEW Technical report 2021/03

Soil and Land Hub

A collaboration between the Sustainable Soils Groups in DEW and PIRSA

Government of South Australia
Department for Environment and Water

Government of South Australia
Department of Primary Industries and Regions

Department for Environment and Water

Government of South Australia

June 2021

81-95 Waymouth St, ADELAIDE SA 5000

Telephone +61 (8) 8463 6946

Facsimile +61 (8) 8463 6999

ABN 36702093234

www.environment.sa.gov.au

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ISBN 978-1-922027-00-9

Preferred way to cite this publication

Schapel A*, Herrmann T, Sweeney S and Liddicoat C (2021). *Soil Carbon in South Australia: Volume 4 – Benchmarks and Data analysis for the Agricultural Zone 1990-2007*. DEW Technical Report 2021/03, Government of South Australia, Department for Environment and Water, Adelaide.

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Front Cover: Plant roots are a key mechanism in building soil carbon in agricultural soils (Source: Amanda Schapel - PIRSA)

Foreword

The Department for Environment and Water (DEW) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provides the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEW's strong partnerships with educational and research institutions, industries, government agencies, Natural Resources Management Boards and the community ensures that there is continual capacity building across the sector, and that the best skills and expertise are used to inform decision making.

John Schutz
CHIEF EXECUTIVE
DEPARTMENT FOR ENVIRONMENT AND WATER

Acknowledgements

Volume 4 of the Soil Carbon in South Australia Series provides soil organic carbon concentration benchmarks for the Agricultural Zone based on soil test data during the period 1990-2007. The benchmarks provide a value to monitor change for future comparison and a guide to assess if the soil has an opportunity to store more carbon. This publication is produced by the Soil and Land Hub, which is a collaboration between the Department for Environment and Water (DEW), and the Department of Primary Industries and Regions (PIRSA).

The authors wish to thank Mary-Anne Young PIRSA for reviewing this document and Trevor Hobbs (DEW) for assisting with editing.

"We can't move forward without knowing where we have been"

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Fast Facts

Soil carbon benchmarks and baseline

Benchmarks for soil organic carbon (SOC) concentration across the South Australian agricultural zone were determined based on the combined dataset of soil test results for the period 1990-2007.

The proportion of soil samples analysed within low, medium and high SOC ranges for soil texture, land use and agricultural districts were defined.

SOC baselines for 1990 (Kyoto Protocol) and 2005 (Paris Agreement) were also determined.

Key figures for the agricultural zone

Benchmark topsoil SOC concentration (mean value)

- 1990-2007: 1.77%
- Texture:
  - sand 1.12%
  - sandy loam 1.79%
  - loam 1.96%
  - clay 1.66%
- Land use:
  - pasture 2.82%
  - forestry 2.26%
  - cropping 1.42%
  - orchard / vineyard 1.33%

Soil texture

SOC concentrations increased linearly with increasing clay content for sand to loam textured soil. As clay content further increased there was an unexpected plateau for clay loam and a decline in SOC for clay-textured soil.

Overall, 42% of topsoil samples were in the high (SOC >1.0%), 37% in the moderate (SOC 0.5-1.0%) and 20% in low (SOC < 0.5%) SOC range.

Proposed new SOC standards were derived from the 25th and 75th percentiles for low and high SOC range.

Land use

Pasture soils had the highest SOC concentration followed by forestry, annual horticulture, cropping and the lowest were in orchard / vineyards.

Pasture soils had a wider range of SOC values between the 25th and 75th percentile by texture than cropping soils. SOC values for pasture are above the agricultural zone average whilst those for cropping soil are below.

SOC concentration under orchards and vineyards varied greatly.

Over time

SOC concentration increased at a rate of 0.08% per annum (p.a.) during 1990 to 2007.

This was largely driven by an increase in SOC of 0.11% p.a. in pasture soils with a smaller increase of 0.04% p.a in cropping soils.

Note: Average SOC concentration can be affected by the mix of land use in the analysis. A decline in the proportion of cropping samples over time could be contributing to the apparent increase in SOC.

Agricultural Districts

Lower Murray and Yorke Peninsula were identified as having higher SOC than would be expected based on the growing season rainfall.

The Lower North and Upper South East had lower SOC than would be expected based on the growing season rainfall.

Average topsoil SOC did not exceed 2% unless rainfall was greater than 600 mm (annual) or 500 mm (growing season).

Distribution of carbon

The majority (about 60%) of SOC in the 0-30 cm depth occurs in the surface 10 cm. Values ranged from 53 to 63% depending on texture.

The SOC concentration in the subsoil (>30 cm depth) was about 30% of the 0-10cm value.

Future work

- Determine a way to define SOC values since 2008 to understand recent SOC trends;
- Understand the reasons for variability within texture, land use, rainfall and location;
- Closely examine the data to quantify the State SOC opportunity and identify suitable areas with the greatest potential for increased carbon storage.

Executive Summary

This report establishes soil organic carbon (SOC) concentration benchmarks and baselines for the South Australian agricultural zone based on soil test data for the period 1990-2007. The meta-analysis included approximately 36,000 soil test results collated predominately from the State Government-managed Analytical Crop Management Laboratory over that period. SOC levels and the proportion of soil samples analysed within low, medium and high SOC ranges for soil texture, land use and agricultural districts were defined.

The key findings include:

- Benchmark SOC concentrations were determined for the South Australian agricultural zone and individual agricultural districts by texture and land use to identify the opportunity to store additional SOC.
- SOC values increased linearly with increasing clay concentration for sand to loam textured soil. However, there was a plateau for clay loam and an unexpected decline in SOC for clay-textured soils that requires further investigation.
- Compared to the topsoil[1], the subsurface soil held approximately 75% of topsoil SOC concentration whilst the subsoil was approximately 30% (Figure 4). Under a conducive environment, this indicates an opportunity to increase SOC below the topsoil.
- Agricultural zone SOC baselines for 1990 (Kyoto Protocol) and 2005 (Paris Agreement) were established and provide a value for future comparison to determine if changes in SOC have occurred.

Land Use

- Pasture soils had higher mean SOC concentration (2.82%) and a wider range of SOC concentration between the 25th and 75th percentile (1.73 to 3.77%) than cropping soils (mean 1.42% and range 0.96 to 1.70%).
- Mean SOC concentration within differing soil textures for pasture were above the agricultural zone average whilst those for cropping soil are below (Figure 1).

Change over time

- SOC concentration increased at a rate of 0.08%[2] per annum (p.a.) during the period 1990 to 2007
- This was largely driven by an increase in SOC of 0.11% p.a. in soils under pasture with a small but positive increase of 0.04% p.a. in cropping soils. The SOC values under orchards and vineyards varied greatly and requires further investigation.

Agricultural Districts

- Agricultural districts were identified as having higher SOC (Lower Murray and Yorke Peninsula) and lower SOC (Lower North and Upper South East) than was expected based on the growing season rainfall.
- Approximately half of the districts had stable to small annual change in SOC concentration ~0.01 to 0.02%, a third had an annual increase of 0.03 to 0.04% and a fifth had an annual increase of 0.06-0.07% (Lower Murray, Yorke Peninsula and Central Hills/ Fleurieu Peninsula/ Kangaroo Island). Whilst the Lower South East was identified as a having stable to small annual SOC change, the trend is declining over time. This could indicate an increase, rather than decrease, in greenhouse gas emissions.

Understanding the important factors driving the changes in SOC concentration will identify where the opportunity for improved SOC storage in South Australian agricultural zone is by soil texture, land use and agricultural district.

[1] Topsoil is defined as 0-10 or 0-15 cm depending on land use, subsurface 10-30 or 15-30 cm, and subsoil > 30 cm.
[2] Throughout this report SOC concentration (%) is defined on a mass basis representing g C/100 g soil in the fine earth (< 2 mm) fraction.

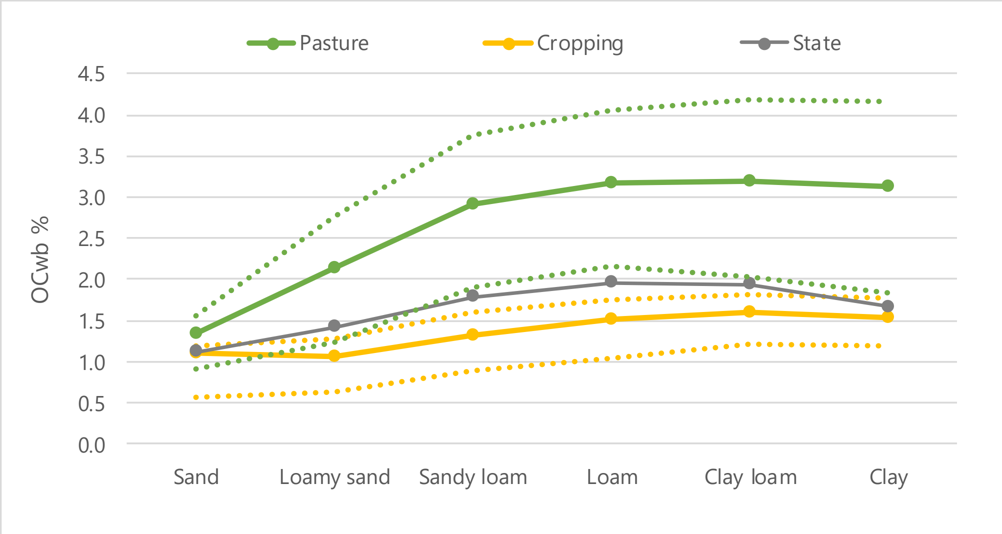


Figure 1. Mean topsoil SOC, upper (75%) and low (25%) bands (dotted) for pasture, cropping and all SA agricultural soils. Note the pasture soils sit above, and cropping soils below, the weighted mean for the agricultural zone.

Introduction

Agricultural soils are important not only for their critical role in growing food to feed the world but also their contribution to the balance of greenhouse gas emissions. Globally, most agricultural systems have lost between 40 to 70% of their natural soil carbon and there is a common belief that many agricultural soils continue to lose organic carbon (SOC). Hence it is important to identify and implement practices that minimise or reverse the decline in SOC.

The 1990 Kyoto Protocol and 2015 Paris Agreement includes a worldwide commitment to reduce greenhouse gas concentrations. Where greenhouse gas emissions cannot practically or economically be reduced, offsets need to be secured. An internationally recognised priority area of interest is sequestration of carbon in soils.

This report establishes SOC concentration benchmarks and baseline for the agricultural zone of South Australia. In the absence of long-term SOC monitoring sites across the state, examination of soil analysis results collated predominately from the State Government managed Analytical Crop Management Laboratory from 1990-2007.

These values are critically important as they establish values for comparison, identification of opportunities to improve SOC and essential information to guide future directions.

Factors that affect soil organic carbon

SOC has attracted significant attention for its critical role in maintaining or regenerating agricultural soils. SOC is essential for a number of physical, chemical and biological processes (Table 1).

The amount of SOC in soil is the balance between the rate of input (plant residue, composts or manures) and output (CO_2 release from microbial decomposition, leaching and soil erosion). There are a number of factors that individually or in combination affect the total amount and distribution of SOC in the profile, including soil type, climate, topography and soil biota (Figure 2).

The potential of a soil to increase SOC relies on the possibility of increasing SOC inputs so they exceed outputs (e.g. from microbial decomposition or erosion), the conversion of SOC inputs into more stable forms of SOC for long-term storage (as the less stable forms are more quickly lost from the soil following disturbance) and the capacity of the soil to store more SOC (largely based on clay content and mineralogy). If any of these factors change, increased SOC storage may occur, only up to the point when a new SOC equilibrium between inputs and microbial activity has been reached.

SOC may not increase in soil systems for a number of reasons. In soils that that are functioning at high capacity, the SOC is constantly cycling through the living, actively decomposing, and stable fractions providing many soil health benefits, but not always affording a carbon sequestration benefit. Conversion of SOC inputs to more stable forms can be limited in soils where the availability of nutrients, particularly nitrogen, phosphorous and sulphur, restricts conversion by biological activity.

It is imperative to understand the distinction and be able to differentiate systems that have the capacity to increase SOC through remediation or change in management practice, and those soils that are already near their potential SOC level. This report explores the notion of expected ranges and upper potential SOC levels by examining the distribution of SOC concentration found in similar soils within different rainfall zones.

Table 1. Role of carbon in soil.

Physical	Chemical	Biological
better structural stability (aggregation)	improved cation exchange	increased biological activity
lower bulk density	source of nutrients	increased diversity
rapid infiltration of water	continual release of nutrients	improved suppression of soil borne pathogens
better drainage	sorption and deactivation of contaminants	
better root growth		
less erosion		
improved water holding capacity		

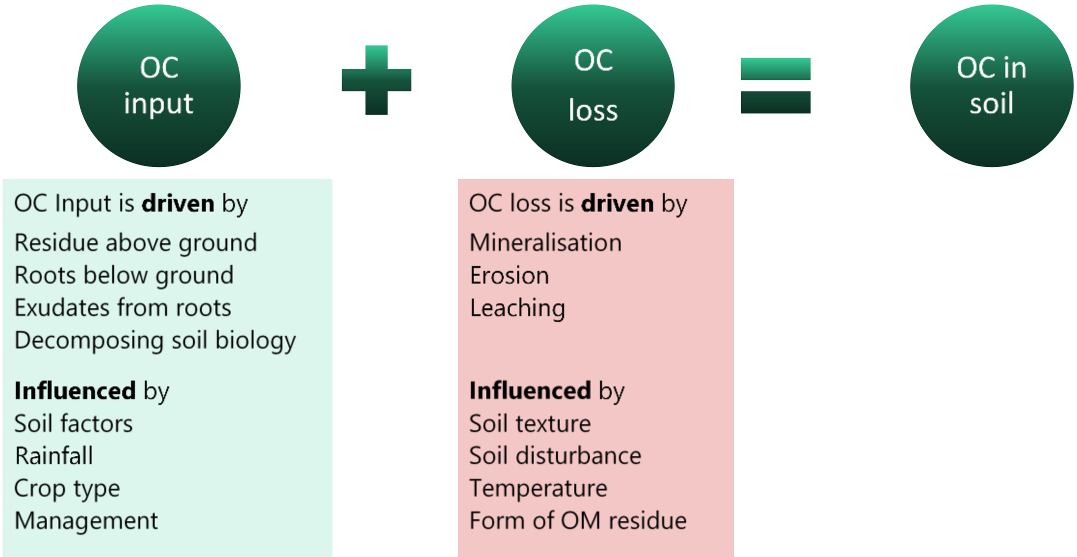


Figure 2. Factors that influence SOC

Method

Benchmarks and Baseline for the Agricultural Zone

Due to the absence of long-term soil monitoring sites in the South Australian agricultural regions, soil analytical results predominantly from the State Government's Analytical Crop Management Laboratory (ACML) service (1990-2007), along with results from private companies and natural resource management projects, were collated into a single dataset. Selection of suitable data was based on records with SOC, postcode[3], sampling date, sampling depth, soil texture and land use. Duplicate records were identified and removed. Records were organised into agricultural districts, soil texture and land use categories.

The combined dataset is robust with 36,163 soil samples (34,186 from the topsoil), 35,618 samples with soil texture, 34,189 with agricultural district and 24,996 samples with land use recorded. *Note: land use was not documented in the dataset for 1992-1994 and may affect results.*

Meta-analysis of the dataset determined the mean (either ordinary or weighted[4] for key groups), minimum, maximum and percentiles by year, soil texture, agricultural district, land use and their combinations. To reduce variability in SOC results due to seasonal fluctuations, a rolling 3-year mean was used, averaging the current and two previous years. The proportion of samples within categories and SOC ranges (low, moderate and high, described below) were determined.

As soil texture (clay content) largely determines the potential SOC storage in soil, it is critical to consider when defining SOC categories. SOC standards for low, moderate and high ranges were previously developed for the topsoil layer of South Australian agricultural soil (Table 2) and were used here to allocate samples to SOC categories.

Topsoil was defined as 0-10 cm for cropping and 0-15 cm for horticultural and grazing, 10-30 or 15-30 cm for subsurface, and below 30 cm for subsoil. The greatest number of samples were in the topsoil layer as most soil tests were undertaken to determine macro nutrient concentrations. Therefore, the low number of samples from subsurface and subsoil described in this report provide an indication of trends rather than a defined benchmark.

SOC analysis was by the Walkley Black wet oxidation method - the most common test offered by laboratories in Australia. This test provides an approximate measure of SOC due to an incomplete reaction in the oxidation of the organic matter (~80% of total SOC). However, it does not measure inorganic carbonates (inorganic C) that are often present in South Australian soils. The use of catalysed, high temperature combustion is a requirement to measure soil C under the Carbon Farming Initiative (Australian Government 2018). However, in standard form this analytical method measures carbonates, and high concentrations of inorganic C can make small changes in SOC difficult to detect. Chemically removing carbonates increases the accuracy of the total SOC measurement and is essential for South Australian soils with carbonate present.

Limitations of dataset

It is acknowledged that attributing baseline and benchmark SOC levels based on laboratory analysis introduces uncertainty due to different and/or inaccurate methods of sample collection, potential contamination of samples, use of different laboratories, attribution to agricultural district based on postcode and/or hundred and sample numbers not representative of the land use within the agricultural zone or district . However, the large number of samples from the dataset largely counteract the uncertainties resulting in high confidence in the baseline and benchmark SOC results (1990-2007).

[3] Postcode was the one field common to the majority of records. However, the postcode could be the landholders postal address rather than the actual location of the property. Where available the Hundred rather than postcode was used to allocate to the agricultural district.

[4] The weighted arithmetic mean is similar to an ordinary arithmetic mean except that instead of each of the data points contributing equally to the final average, some data points contribute more than others. Weighted means were based on the count of samples multiplied by the SOC concentration divided by the total number of samples and calculated for soil texture and land use.

Table 2. SOC standards for the topsoil layer of South Australian agricultural soil with consideration of soil texture (Standards B. Hughes PIRSA).

	Sand to Loamy sand	Sandy loam	Loam	Clay loam to Clay
Low	< 0.5	< 0.7	< 0.9	< 1.2
Moderate	0.5 – 1.0	0.7 - 1.4	0.9 - 1.8	1.2 – 2.0
High	> 1.0	> 1.4	> 1.8	> 2.0

Soil Carbon Benchmarks

Soil texture

KEY POINTS

- SOC concentration values increase with increasing clay content.
- However, plateau and unexpected decline of SOC concentration from clay loam to clay soil requires further investigation.
- The highest proportion of samples in the low SOC range are for sand, clay loam and clay topsoil textures.

As expected, SOC % values increased with increasing clay content (texture). Average SOC values were lowest in sand (1.12%) and highest in loams (1.96%) with a plateau in SOC for clay loam (1.93%) and an unexpected decline for clay (1.63%) textures. The lower than expected values for the clay loam and clay textures may be because of rainfall limiting biomass production (e.g. less permeable soils or higher moisture content required to overcome the 'wilting point' or lower storage limit) and hence lower plant growth and less biomass SOC input into the soil, a physical restriction or biological reason such as increased microbial activity. The difference in actual and potential SOC storage requires further investigation.

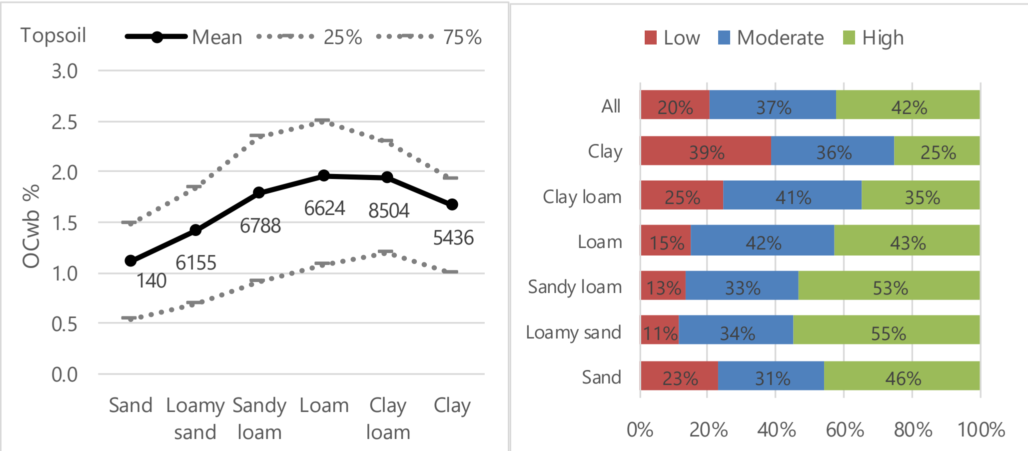


Figure 3. Topsoil average SOC, number of samples, upper (75%) and lower (25%) bands (left) and proportion of texture samples in the high, moderate and low SOC range (right) by soil texture.

Table 3. Agricultural zone SOC benchmarks for topsoil by texture displaying the mean and percentile values.

	Count	Mean	25%	40%	50%	60%	75%
Sand	140	1.12	0.54	0.76	0.93	1.13	1.49
Loamy sand	6155	1.42	0.69	0.91	1.08	1.30	1.83
Sandy loam	6788	1.79	0.90	1.17	1.39	1.67	2.34
Loam	6624	1.96	1.07	1.33	1.53	1.80	2.50
Clay loam	8504	1.93	1.20	1.44	1.60	1.79	2.29
Clay	5436	1.66	1.00	1.25	1.40	1.57	1.92
Weighted mean		1.77	0.99	1.23	1.41	1.64	2.19

Depth of topsoil was categorised as 0-10 cm for cropping and 0-15 cm for horticultural and pasture samples. Subsurface was 10-30 cm or 15-30 cm and subsoil was greater than 30 cm from the soil surface.

Subsurface SOC values mirror those of the topsoil and are on average 74% of topsoil values (Figure 4). Subsoil values are 36% of the topsoil values but follow the expected linear increase of SOC with clay content. When considering the 0-30 cm soil depth, approximately 60% of the SOC concentration is in the topsoil with 40% in the subsurface (Table 4).

Under a conducive environment, there should be an opportunity to increase SOC below the topsoil.

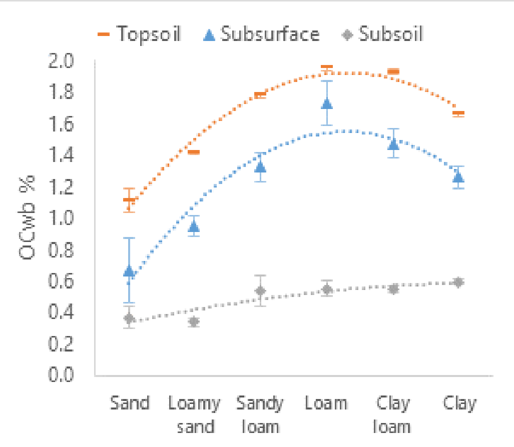


Figure 4. Average SOC (%) fitted curve for soil layers, topsoil, subsurface and subsoil.

Table 4. SOC values (%) by texture for soil layers for all samples.

	Sand	Loamy sand	Sandy loam	Loam	Clay loam	Clay	Weighted mean
Mean SOC Concentration (%)							
Topsoil	1.12	1.42	1.79	1.96	1.93	1.66	1.77
Subsurface	0.67	0.95	1.33	1.73	1.48	1.26	1.32
Subsoil	0.37	0.34	0.54	0.56	0.55	0.60	0.54
Proportion of SOC compared to the topsoil (%)							
Subsurface	60	67	74	88	77	78	74
Subsoil	33	24	30	29	28	36	31

Land use

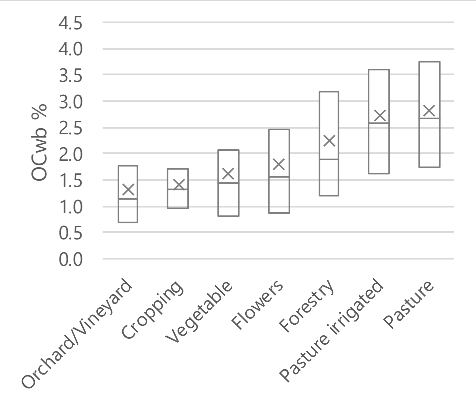
KEY POINTS

- Highest SOC concentration in pasture, lowest in orchard / vineyards.
- Greatest proportion of samples in low SOC range in orchard / vineyard followed by flowers and vegetables.
- Pasture has greatest proportion of samples in high SOC range.

Pasture soils had the highest SOC concentration (2.82%) followed by forestry, annual horticulture, cropping and the lowest in orchard / vineyards (Figure 5). Pasture soil also had the highest proportion of samples in the high SOC range whilst cropping and orchard / vineyard soils had the lowest.

Cropping soils had the narrowest range of SOC values between the 25th and 75th percentile (Figure 6), suggesting there may be an opportunity to explore different practices that could increase SOC storage. The wider range of SOC values in pasture soils also indicates opportunities to identify practices that lead to higher SOC values. Nevertheless, the result could also reflect the broad range of rainfall zones and in part be a result of contamination from fine organic material (mainly roots) present in the soil leading to higher values than in other land uses. This requires further investigation.

Whilst the plateau of SOC concentration with increasing soil texture was observed for all land uses (Figure 6), the sharp decline for clay texture, as shown in Figure 3Figure 3, was not observed. This could indicate that the decline is not linked to these key land uses or is linked to the 10,000+ samples where land use was not recorded.



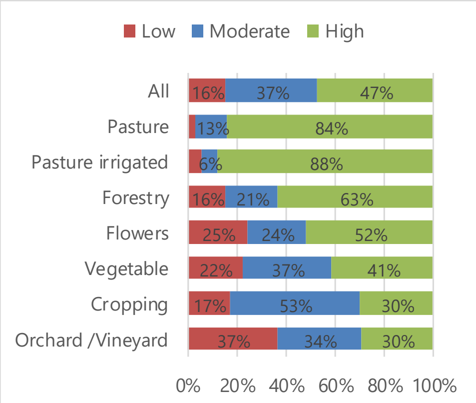


Figure 5. Topsoil average SOC (X), upper (75%) and lower (25%) bands (left) and proportion of samples in the high, moderate and low SOC range for key land uses (right).

Table 5. Agricultural zone SOC (%) benchmark for topsoil by land use and displaying the mean weighted mean and percentile values.

	Count	Mean	25%	40%	50%	60%	75%
Orchard/Vineyard	3184	1.33	0.69	0.94	1.13	1.36	1.77
Cropping	12279	1.42	0.96	1.18	1.31	1.45	1.70
Vegetable	645	1.63	0.81	1.19	1.43	1.69	2.08
Flowers	107	1.80	0.85	1.14	1.56	1.91	2.45
Forestry	161	2.26	1.19	1.49	1.89	2.35	3.19
Pasture irrigated	146	2.72	1.63	2.23	2.58	2.97	3.62
Pasture	7174	2.82	1.73	2.28	2.66	3.08	3.77
Weighted mean		1.85	1.16	1.49	1.71	1.96	2.37

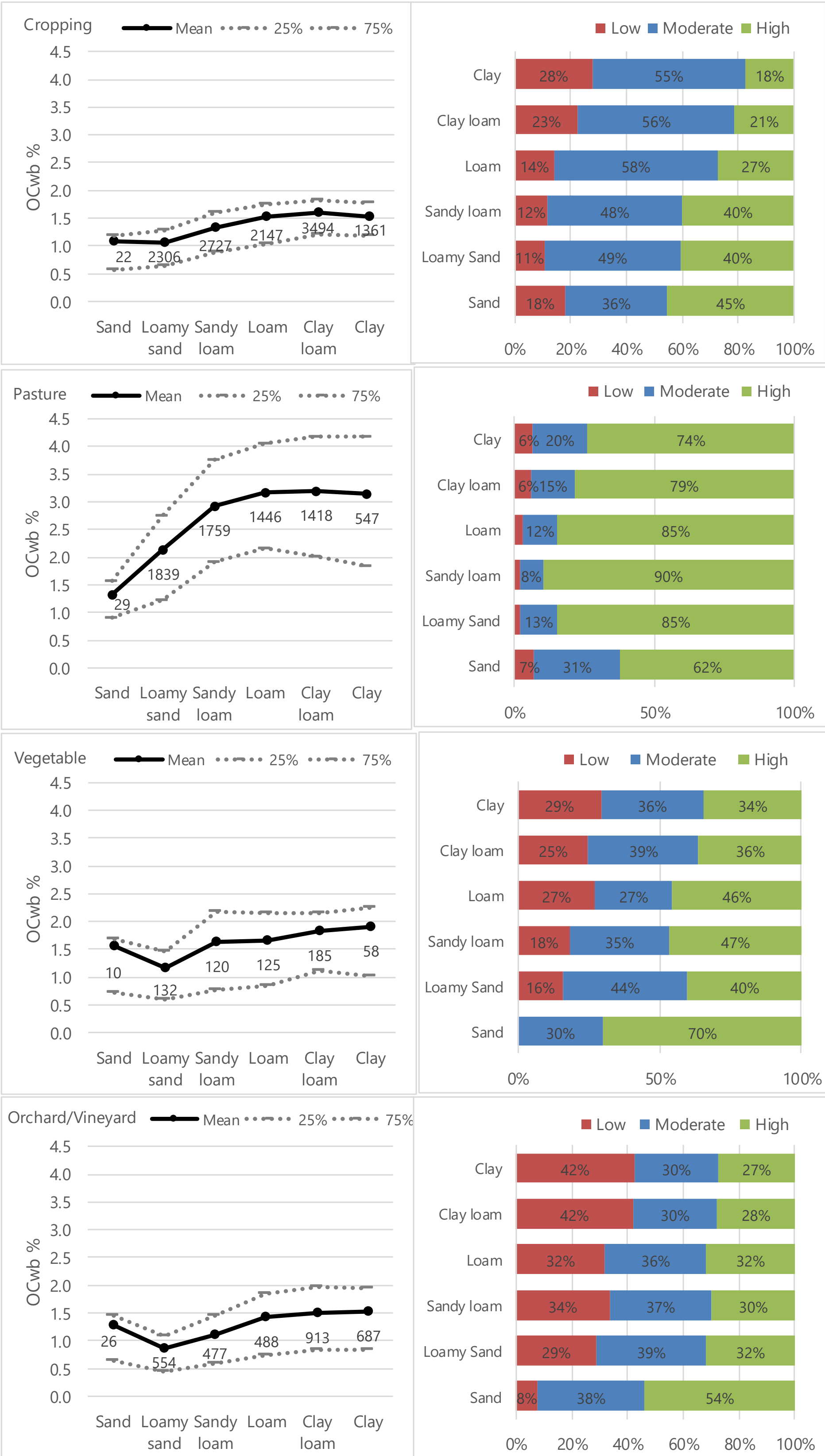


Figure 6. Topsoil average SOC %, number of samples, upper (75%) and lower (25%) bands (left) and proportion of texture samples in the low, moderate and high SOC range (right) for land use by texture.

Table 6. Agricultural zone SOC (%) benchmark for topsoil by land use and texture displaying the mean and percentile values.

Land use	Texture	Count	Mean	25%	40%	50%	60%	75%
Cropping	Sand	22	1.10	0.56	0.72	0.92	1.10	1.19
	Loamy sand	2306	1.06	0.64	0.78	0.88	1.00	1.27
	Sandy loam	2727	1.32	0.88	1.06	1.18	1.31	1.59
	Loam	2147	1.52	1.03	1.22	1.36	1.50	1.74
	Clay loam	3494	1.61	1.21	1.40	1.50	1.61	1.82
	Clay	1361	1.54	1.18	1.35	1.45	1.55	1.77
Pasture	Sand	29	1.34	0.91	1.01	1.21	1.47	1.56
	Loamy sand	1839	2.13	1.24	1.66	1.95	2.24	2.75
	Sandy loam	1759	2.92	1.91	2.44	2.77	3.18	3.76
	Loam	1446	3.17	2.16	2.76	3.11	3.43	4.06
	Clay loam	1418	3.19	2.02	2.74	3.16	3.55	4.19
	Clay	547	3.14	1.84	2.56	3.04	3.51	4.17
Pasture irrigated	Sand	0						
	Loamy sand	27	2.31	1.27	1.59	1.85	2.22	2.85
	Sandy loam	35	2.42	1.47	1.79	2.29	2.64	3.06
	Loam	37	2.92	2.11	2.52	2.65	3.33	3.70
	Clay loam	27	3.31	2.53	3.09	3.21	3.57	3.83
	Clay	16	2.77	1.00	2.02	3.17	3.78	4.23
Orchard / Vineyard	Sand	26	1.28	0.64	0.93	1.13	1.37	1.46
	Loamy sand	554	0.86	0.45	0.61	0.74	0.90	1.08
	Sandy loam	477	1.12	0.59	0.77	0.90	1.09	1.45
	Loam	488	1.43	0.74	1.09	1.28	1.48	1.84
	Clay loam	913	1.50	0.83	1.14	1.34	1.56	1.96
	Clay	687	1.53	0.84	1.15	1.38	1.59	1.95
Vegetable	Sand	10	1.56	0.71	1.39	1.53	1.58	1.68
	Loamy sand	132	1.15	0.59	0.72	0.84	0.99	1.47
	Sandy loam	120	1.63	0.76	0.98	1.14	1.43	2.17
	Loam	125	1.67	0.85	1.30	1.58	1.80	2.16
	Clay loam	185	1.83	1.13	1.49	1.67	1.87	2.15
	Clay	58	1.92	1.01	1.49	1.71	1.79	2.25
Forestry	Sand	0						
	Loamy sand	41	1.68	0.87	1.20	1.34	1.54	2.12
	Sandy loam	23	2.15	1.10	1.30	1.55	2.07	3.35
	Loam	32	2.50	1.47	1.97	2.34	2.48	3.14
	Clay loam	33	2.70	1.64	2.33	2.60	2.97	3.69
	Clay	32	2.37	1.19	1.42	1.93	2.57	3.92
Flowers	Sand	0						
	Loamy sand	4	0.78	0.62	0.71	0.81	0.91	0.97
	Sandy loam	33	1.99	0.94	1.49	1.93	2.19	2.45
	Loam	29	1.67	0.75	1.00	1.56	1.76	2.06
	Clay loam	21	1.98	1.03	1.26	1.36	1.60	3.05
	Clay	15	2.02	1.40	2.34	2.36	2.45	2.69

Proposed new SOC standards for soil texture

The data from this report has been used to establish benchmark SOC values for soil texture, land use and agricultural districts. SOC benchmarks for the agricultural zone were determined from the data based on percentiles for soil texture (Table 3), land use (Table 5) and land use by texture (Figure 6 and Table 6).

Benchmark SOC values were created for agricultural districts for texture and land use (Appendix 1).

The benchmarks provide a useful guide for farmers and advisors to compare topsoil SOC values to the surrounding agricultural district and zone average, and determine if there is the opportunity to store additional SOC.

Although topsoil SOC standards for soil texture have been used for many years in South Australia (Table 2) the standards can be updated based on the results from approximately 35,000 soil sample results analysed in this report. Topsoil SOC ranges based on the percentiles from the dataset where the 25th percentile is equivalent to the low and 75th percentile the high SOC range for all land uses in the agricultural zone (Table 7) and for key land uses, pasture, cropping and orchard / vineyard (Table 8Table 8).

The new standards have increased both the low and high SOC range for all textures except clay where there has been a decrease reflecting the decline in SOC values observed in the report. The high SOC range has substantially increased (>0.6%) for loamy sand, sandy loam and loam soils.

Table 7. Proposed new SOC concentration standards for the topsoil of South Australian agricultural zone with consideration to soil texture compared to SOC standards currently used.

	NEW				OLD		
	Low	Moderate	High		Low	Moderate	High
Sand	<0.5	0.5 - 1.5	>1.5		<0.4	0.4 – 1.0	>1.0
Loamy sand	<0.7	0.7 - 1.8	>1.8		<0.4	0.4 – 1.0	>1.0
Sandy loam	<0.9	0.9 - 2.3	>2.3		<0.6	0.6 - 1.4	>1.4
Loam	<1.1	1.1 - 2.5	>2.5		<0.8	0.8 - 1.8	>1.8
Clay loam	<1.2	1.2 - 2.3	>2.3		<1.1	1.1 – 2.0	>2.0
Clay	<1.0	1.0 - 1.9	>1.9		<1.1	1.1 – 2.0	>2.0
All textures	<1.0	1.0 – 2.2	>2.2				

Table 8. New topsoil SOC concentration benchmarks for key land uses in South Australian agricultural soil with consideration to soil texture.

	Pasture			Cropping			Orchard / Vineyard		
	Low	Moderate	High	Low	Moderate	High	Low	Moderate	High
Sand	<0.9	0.9 - 1.6	>1.6	<0.6	0.6 – 1.1	>1.1	<0.6	0.6 - 1.5	>1.5
Loamy sand	<1.2	1.2 – 2.8	>2.8	<0.6	0.6 - 1.3	>1.3	<0.5	0.5 - 1.1	>1.1
Sandy loam	<1.9	1.9 – 3.8	>3.8	<0.9	0.9 - 1.3	>1.3	<0.6	0.6 – 1.5	>1.5
Loam	<2.2	2.2 – 4.1	>4.1	<1.0	1.0 – 1.7	>1.7	<0.7	0.7 – 1.8	>1.8
Clay loam	<2.0	2.0 – 4.2	>4.2	<1.2	1.2 – 1.8	>1.8	<0.8	0.8 - 2.0	>2.0
Clay	<1.8	1.08- 4.2	>4.2	<1.2	1.2 - 1.7	>1.7	<0.8	0.8 – 2.0	>2.0
All textures	<1.7	1.7 – 3.8	>3.8	<1.0	1.0 – 1.7	>1.7	<0.7	0.7 – 1.8	>1.8

Over time

KEY POINTS

- Annual increase in SOC of 0.08 % from 1990 to 2007.
- Largely driven by an increase in SOC of 0.11% p.a. of soils under pasture with a small but positive increase of 0.04% p.a. in cropping soils.
- Large variability in SOC values for orchards/vineyards over time requires further investigation.

South Australian agricultural soils increased in SOC by 0.08% per annum over the period 1990-2007. Annual SOC fluctuated over time showing changes by season with a general increase over time (Figure 7). To reduce variability in SOC results due to seasonal fluctuations, a 3-year rolling mean is shown, incorporating the previous two years of data (Figure 8 and Table 9).

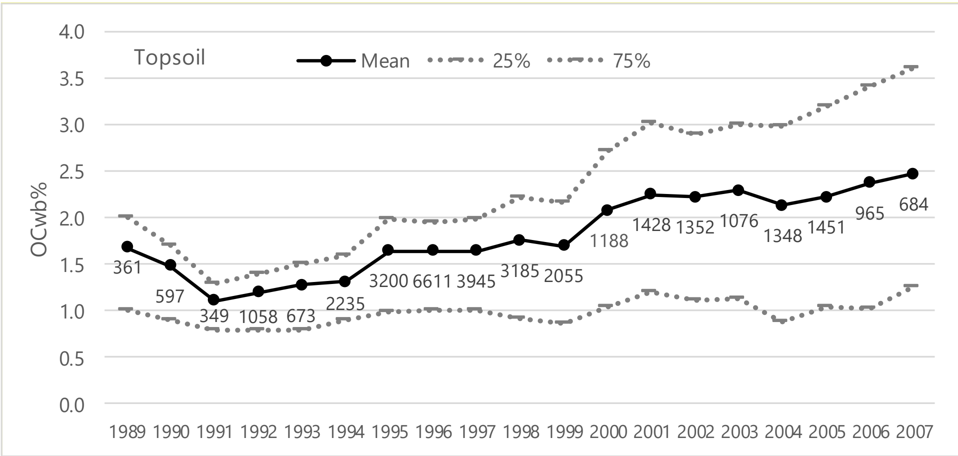


Figure 7. Annual topsoil SOC trends showing average SOC (as measured by Walkley Black method), number of samples, upper (75%) and lower (25%) bands.

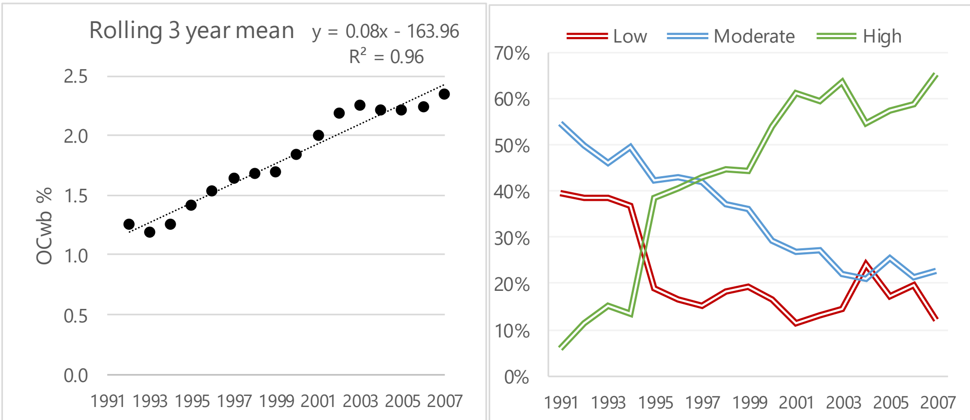


Figure 8. The graphs display the 3-year rolling mean to minimise seasonal effects (left) and the proportion of samples with high, moderate and low SOC ranges over time (right).

Table 9. Average SOC % values for annual and rolling 3-year mean.

	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07
Annual	1.68	1.48	1.11	1.20	1.27	1.32	1.65	1.64	1.65	1.76	1.70	2.08	2.25	2.22	2.29	2.13	2.22	2.37	2.47
Rolling				1.27	1.20	1.26	1.41	1.54	1.65	1.68	1.70	1.84	2.01	2.18	2.25	2.21	2.21	2.24	2.35

Texture

The coefficient of determination (R^2 value) demonstrates a strong relationship between SOC concentration and soil texture (Table 10). This relationship is stronger for the loamy to clay textured soils and could indicate a greater resilience or buffering in SOC over time than for sandier textured soils. The annual increase in SOC % differed between the soil textures ranging from 0.08-0.09% for loamy sand, clay and clay loam to 0.10-0.12% for sandy loam, sand and loams. Variation in SOC concentration is apparent over time (Figure 9) and along with the annual increase in SOC concentration, could indicate that there are more limitations to reaching the potential SOC storage of the sandy and clay textured soil.

Table 10. Annual increase in SOC % and R^2 value for soil textures using the rolling 3-year mean

	All	Sand	Loamy sand	Sandy loam	Loam	Clay loam	Clay
Annual increase SOC %	0.083	0.114	0.079	0.102	0.119	0.093	0.081
R^2	0.96	0.78	0.83	0.89	0.98	0.95	0.91

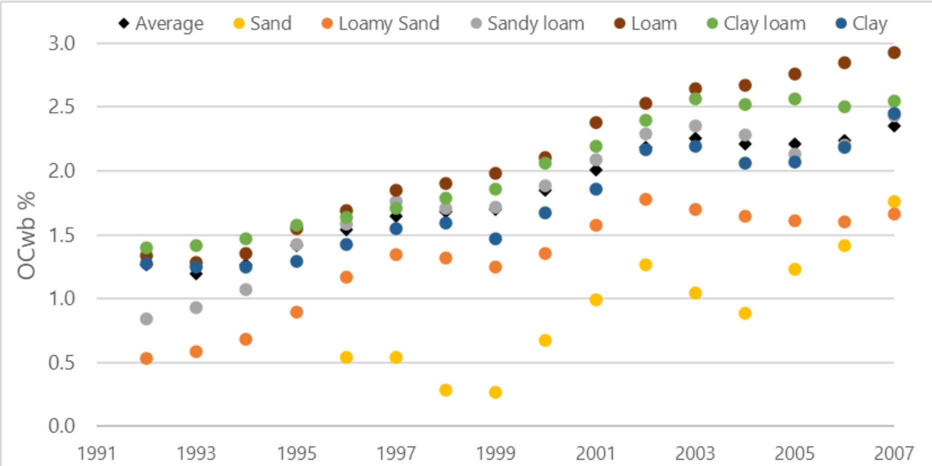


Figure 9. Average topsoil SOC by texture for year using the rolling 3-year mean.

Land use

Topsoil SOC under pasture increased at the highest rate (0.11%) with a smaller but still positive increase in cropping soils (0.04%). SOC concentration under orchard / vineyards were highly variable over time and often had the highest proportion of soil samples in the low SOC range. The R^2 value indicated a strong relationship between SOC concentration and land use for pasture, a moderate relationship for cropping soils and no or very weak relationship for orchard / vineyard soils. (Figure 10 and Table 11).

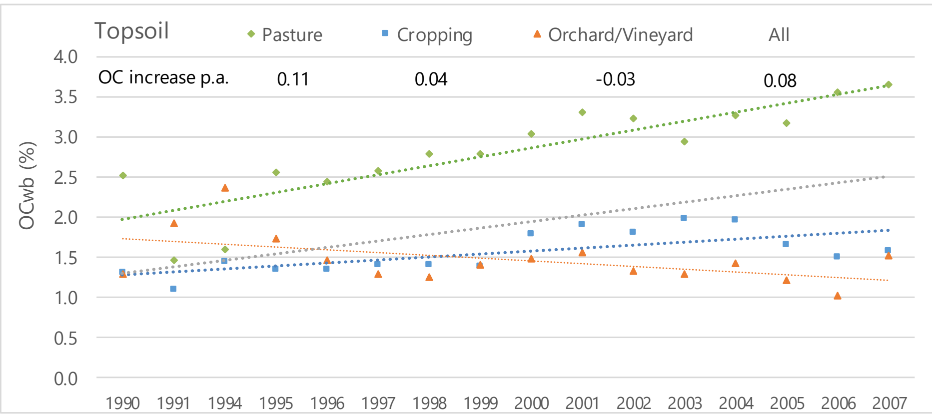


Figure 10. Annual average topsoil SOC trends for key land uses; Cropping, Pasture, Orchard / Vineyard.

Table 11. Annual increase in SOC % and coefficient of determination (R^2) value for key land uses.

	All	Cropping	Pasture	Orchard/Vineyard
Annual increase SOC %	0.081	0.038	0.112	-0.036
R^2	0.96	0.46	0.75	0.28

The composition of land uses in the meta-analysis can affect the average SOC concentration. Overall, the highest proportion of samples were from cropping (36%), pasture (21%) and orchard / vineyard (8%) soils (Table 12). Over time there is a change in proportion of land use samples around the year 2000 from cropping to pasture dominated (Figure 11). This change in composition is likely driving the increase in SOC post 2000 along with a wider range of SOC values between the 25th and 75th percentile.

Table 12. Proportion of topsoil samples in land use categories.

Cropping	Pasture	Orchard / Vineyard	Vegetable	Forestry	Irrigated Pasture	Flowers	Not Recorded
36%	21%	8%	2%	0.5%	0.4%	0.3%	31%

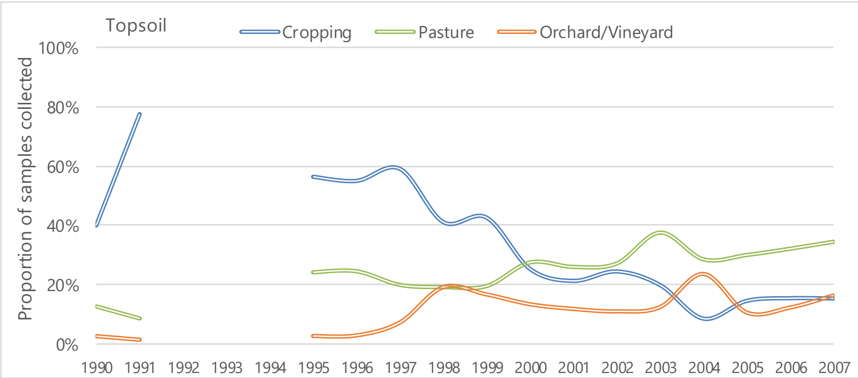


Figure 11. Proportion of samples collected per annum for key land uses; cropping, pasture, orchard / vineyard

Note: land use was not documented in the dataset for 1992-1994.

Soil Carbon Baseline

In the absence of long-term monitoring sites, topsoil SOC concentration baselines were established for key years 1990 (Kyoto Protocol) and 2005 (Paris Agreement) for the South Australian agricultural zone. The baselines (Table 13) will provide SOC concentration for future comparison to evaluate if changes have occurred. SOC concentration for 1990 and 2005 were determined for individual year and to minimise seasonal effect, a rolling three-year (R3y) average including the year prior and post that of interest.

Table 13. Baseline SOC concentration for 1990 and 2005 for the agricultural zone by land use and soil texture.

		Land use				Texture					
		All	**Pasture**	**Crop**	**O/VY**	**Sand**	**Loamy Sand**	**Sandy loam**	**Loam**	**Clay loam**	**Clay**
Actual	1990	1.48	2.51	1.31	1.29	NA	0.43	0.99	1.64	1.43	1.23
R3y	1990-1991	1.27	1.98	1.20	1.61	NA	0.68	1.05	1.56	1.49	1.35
Actual	2005	2.22	3.17	1.65	1.22	2.15	1.65	1.89	2.83	2.65	2.14
R3y	2004-2006	2.37	3.33	1.70	1.21	1.42	1.60	2.20	2.84	2.50	2.18

Agricultural Districts

KEY POINTS

- Proportion of SOC% values in the low range decreases with increasing rainfall.
- Average SOC above 2% only where annual rainfall is greater than 600 mm and predominant land use is pasture.

The data was categorised into agricultural districts as used in PIRSA Crop and Pasture reports (Figure 12). Average topsoil SOC for each district was sorted by rainfall (Table 14). There is a strong relationship between SOC concentration and rainfall with SOC increasing at 0.005% per mm of rainfall (Figure 13). There was no relationship between the annual rate of increase of SOC concentration and rainfall. This suggests that rainfall strongly influenced the amount of SOC in the soil but not the rate that it accumulated. The rate of accumulation is more likely to be influenced by soil texture and management practices (land use).

The Lower Murray and Yorke Peninsula have higher SOC concentration than would be expected for the rainfall. Conversely, the Lower North and Upper South East have lower SOC concentration than would be expected from rainfall. Detailed reports for each agricultural district are presented in Appendix 1.

Figure 12. Agricultural districts used in PIRSA Crop and Pasture reporting.

Table 14. Average annual and growing season (April-October) rainfall, SOC concentration (%) and annual increase in SOC concentration (rolling 3-year) for agricultural districts. Rainfall information supplied by T. Hobbs, DEW Science Information group and covers the years 1982-2018.

	Annual rainfall (mm)	Growing season (mm)	SOC %	Annual increase SOC %	SOC trend over time
Northern Murray Mallee	278	177	0.60	0.0119	↔
Southern Murray Mallee	347	234	0.75	-0.0046	↔
Eastern EP	327	230	0.97	0.0157	↑
Western EP	318	238	1.12	0.0411	↑
Upper North	358	240	1.25	0.0352	↑
Lower North	475	351	1.32	0.0105	↑
Lower Murray	341	233	1.45	0.0685	↑
Upper South East	463	347	1.45	0.0103	↔
Mid North	414	293	1.45	0.0349	↑
Lower EP	432	337	1.46	0.0432	↑
Yorke Peninsula	392	297	1.63	0.0692	↑
Lower SE	636	487	2.47	-0.0185	↔
CH/FP/KI	647	510	2.63	0.0678	↑

*Districts in **green** have higher, and those in **red** have lower SOC concentration than expected by rainfall. SOC trend over time was determined by the R^2 value, below 0.4 a stable (↔) trend and above 0.4 an inclining (↑) trend.*

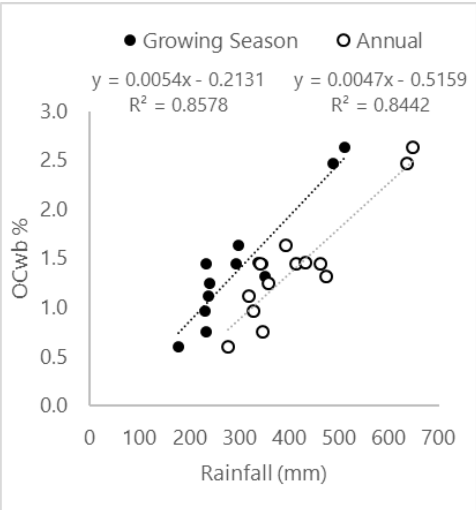


Figure 13. Relationship between average SOC concentration and rainfall (annual and growing season). SOC and rainfall data is averaged for all years

The proportion of soil samples collected from land uses (Table 15) will affect SOC values (Figure 14). In the Lower North, there are higher numbers in orchard/vineyard and lower in cropping categories than would be expected, potentially reducing SOC below anticipated. Further work is required to assess if the proportion of soil samples are representative of the agricultural zone and districts.

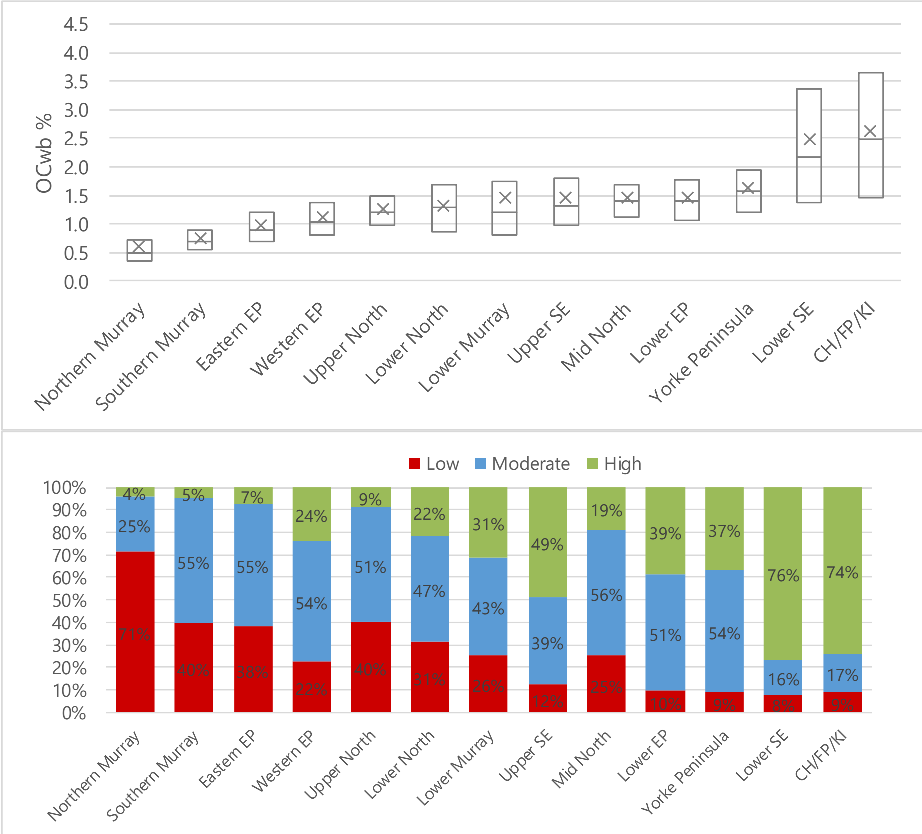


Figure 14. Topsoil average SOC (X), upper (75%) and lower (25%) bands (top) and proportion of samples in the high, moderate and low SOC range for agricultural districts (bottom).

Table 15. Proportion of land use for each agricultural district represented by soil test.

Cropping District	Cropping	Orchard / Vineyard	Pasture	Pasture Irrigated	Vegetable	Forestry	Flowers
Lower Eyre Peninsula	92%	1%	6%	0%	1%	0%	0%
Eastern Eyre Peninsula	95%	0%	5%	0%	0%	0%	0%
Western Eyre Peninsula	99%	0%	1%	0%	0%	0%	0%
Lower North	47%	26%	17%	0%	7%	1%	2%
Mid North	82%	10%	7%	0%	1%	0%	0%
Upper North	90%	2%	7%	0%	0%	0%	0%
Yorke Peninsula	97%	0%	3%	0%	0%	0%	0%
CH/FP/KI	9%	22%	63%	1%	3%	1%	1%
Lower Murray	56%	9%	28%	1%	5%	1%	0%
Southern Murray Mallee	91%	3%	4%	0%	2%	0%	0%
Northern Murray Mallee	45%	46%	8%	0%	1%	0%	0%
Lower South East	20%	15%	57%	1%	5%	2%	0%
Upper South East	54%	12%	31%	1%	2%	0%	0%
Mean	**52%**	**13%**	**30%**	**1%**	**2%**	**1%**	**0%**

Summary

Soil organic carbon (SOC) concentration benchmarks and baselines for the South Australian agricultural zone were determined based on soil test data for the period 1990-2007.

Compared to the topsoil, the subsurface soil (10-30 or 15-30 cm) held approximately 75% of SOC whilst the subsoil (> 30 cm) held approximately 30%. This may indicate an opportunity to increase SOC below the topsoil.

As expected, SOC values increased linearly with increasing clay content from sand to loam textures. However, there was a plateau of SOC in clay loam and surprising decline in clay textured soil. The reasons for this discrepancy in potential SOC storage need to be investigated. Productivity in SA is often water-limited, so the increasing wilting point (moisture unavailable to plants) in these soils may partly explain this.

Pasture soil had higher average SOC concentration (2.82%) and a wider range of SOC values between the 25th and 75th percentile by texture than cropping soil (1.42%). SOC values for pasture are above whilst those for cropping soil are below the agricultural zone average (1.77%).

Pasture soil also had the highest proportion of samples in the high SOC range whilst cropping and orchard / vineyard soils had the lowest proportion of samples in the high SOC range. Orchard / vineyard soils had the lowest SOC value and highest proportion of soils in the low SOC range.

According to general consensus, it is thought that most agricultural soils are losing carbon. However, the data presented in this report contradicts that view. South Australian agricultural soils increased SOC concentration on average by 0.08% per annum (p.a) over the period 1990-2007. Topsoil under pasture increased at the highest rate (0.11% p.a.) with a smaller but still positive increase in cropping soils (0.04% p.a.). SOC concentration under orchard / vineyards were highly variable over time and often had the highest proportion of soil samples in the low SOC range. The reasons underlying this variability requires examination.

Agricultural districts were identified with higher SOC (Lower Murray and Yorke Peninsula) and lower SOC (Lower North and Upper South East) than were expected based on the growing season rainfall. These regions require further investigation to understand the reasons behind this and determine if there is opportunity for improved SOC storage.

The Lower South East was identified as having a potential declining trend in SOC over time. This district has some of the highest SOC values and a declining trend could indicate an increase in greenhouse gas emissions. Possible reasons behind the decline could be if the proportion of land use is not representative, subsequently biasing the results or if pasture land was converted to cropping or orchard / vineyard. This is identified for further investigation.

Average topsoil SOC did not exceed 2% unless rainfall was greater than 600 mm (annual) or 500 mm (growing season) – as found in the Lower South East and Central Hills / Fleurieu Peninsula / Kangaroo Island districts.

Proposed new topsoil SOC standards by soil texture for the South Australian agricultural zone were derived from the 25th and 75th percentile benchmark values for low and high SOC range.

Baseline topsoil SOC concentration for the agricultural zone were determined for 1990 (Kyoto Protocol) as 1.27% and 2005 (Paris Agreement) as 2.37%.

Future Work

This work has raised a number of questions that require further investigation. A number of these were highlighted in Volume 1–Soil Carbon Forward Plan. There is a need to:

- Check if the proportion of land uses is within representative ranges to ensure the SOC benchmarks for land use and over time are suitable and not biased.
- Assign gridded rainfall to soil test results based on postcodes to determine a soil carbon baseline and benchmarks for rainfall zones rather than just agricultural districts.
- Find the original soil test database and update the dataset if land use was recorded for 1992-1994.
- Understand the reasons for the variability in orchard / vineyard soils and the high proportion of samples in the low SOC range.
- Understand why there is a plateau of SOC for clay loam and a decline for clay textured soil and not the expected linear increase as reported in the literature.
- Identify why there was higher SOC (Lower Murray and Yorke Peninsula) and lower SOC (Lower North and Upper South East) than expected based on the growing season rainfall and determine the SOC opportunity.
- Determine why the Lower South East agricultural district had a potential declining SOC trend over time.
- Identify practices to increase SOC in subsoil
- Understand what is driving the wider range of SOC values in pasture soils compared to cropping soils and determine if this presents an opportunity for improved SOC storage.
- Identify agricultural districts, land uses and soil textures with the highest SOC opportunity and determine suitable areas for increased carbon storage.
- Further analysis of the dataset to compare benchmarks and averages to SOC stocks (Volume 3).

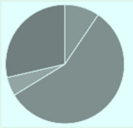
But **most importantly** determine a way to define SOC concentration from 2008 to present to understand recent SOC trends.

Appendix 1

Individual Agricultural District Benchmarks

Lower Eyre Peninsula

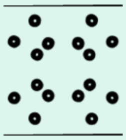
Key Land Use



Cropping: 92%

Pasture: 6%

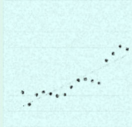
Mean SOC Conc



Ag District: 1.46 %

SA Ag Zone: 1.77%

Annual change SOC



Mean: 0.043% ↑

25th: 0.03% 75th: 0.06%

Texture

Table 16. Benchmark topsoil SOC (%) values for texture displaying the mean and percentile values for Lower Eyre Peninsula compared to the mean for the Agricultural Zone.

	Ag Zone	Ag District Benchmarks						
Texture	**Mean**	**Count**	**Mean**	**25%**	**40%**	**50%**	**60%**	**75%**
Sand	1.12							
Loamy sand	1.42	432	1.08	0.75	0.88	0.98	1.08	1.28
Sandy loam	1.79	542	1.45	1.06	1.23	1.34	1.46	1.70
Loam	1.96	405	1.68	1.28	1.46	1.57	1.69	1.99
Clay loam	1.93	384	1.62	1.35	1.47	1.56	1.65	1.85
Clay	1.66	259	1.47	1.10	1.30	1.42	1.60	1.80
Weighted Mean (all texture)	1.77	2022	1.46	1.10	1.26	1.36	1.48	1.71

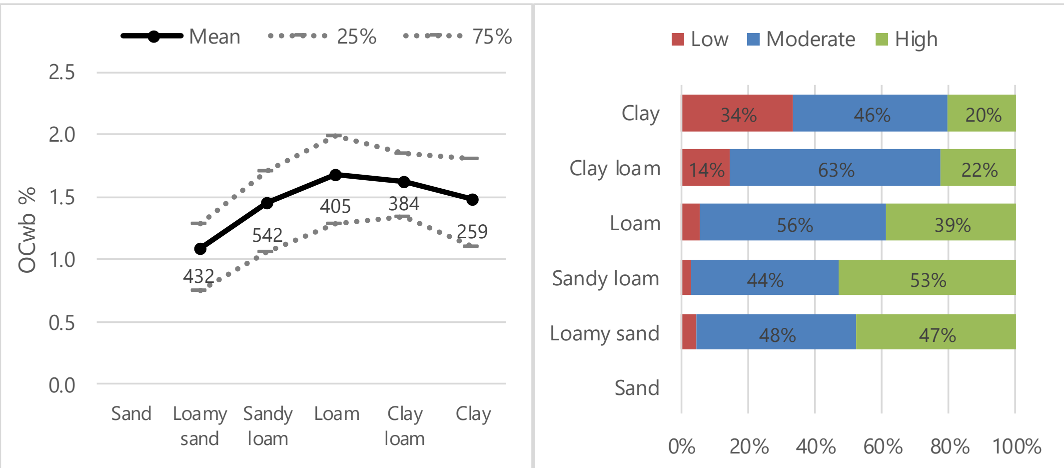


Figure 15. Lower Eyre Peninsula topsoil average SOC %, number of samples, upper (75%) and lower (25%) bands (left) and proportion of texture samples in the high, moderate and low SOC range (right) for texture.

Land use

Table 17. Benchmark topsoil SOC (%) values for land use displaying the mean and percentile values and proportion of land use samples in the high, moderate and low SOC range (right) for Lower Eyre Peninsula.

	Benchmark SOC Concentration					Proportion in SOC range			
Land use	Count	Mean	25%	50%	75%	District Prop (%)	Low	Moderate	High
Cropping	1453	1.43	1.05	1.39	1.71	92	6%	53%	40%
Pasture	95	1.65	1.21	1.48	1.91	6	2%	45%	53%
Orchard / Vineyard	19	1.72	0.96	1.66	2.38	1	22%	22%	56%

Change over time

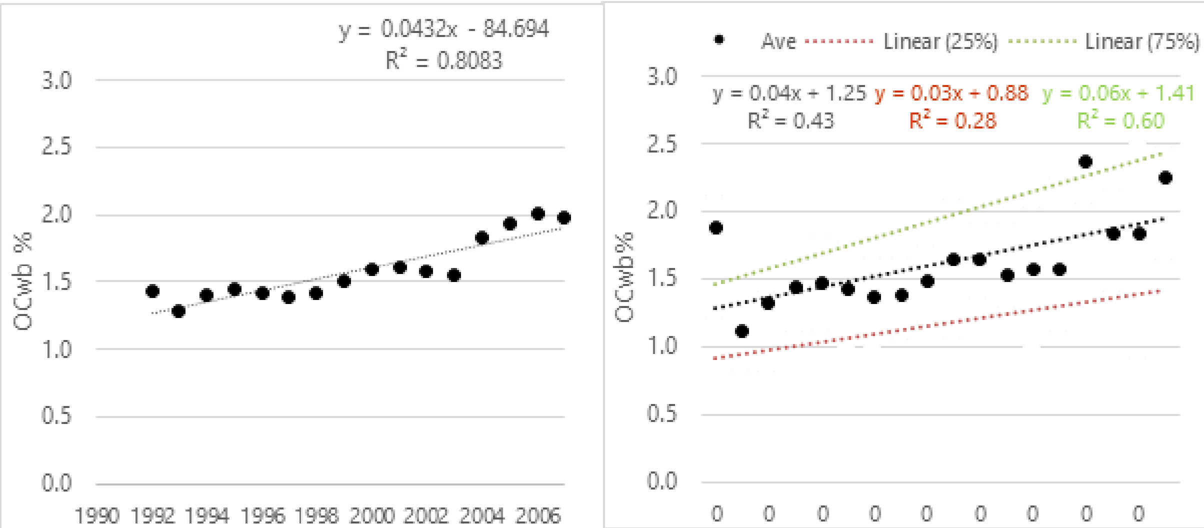
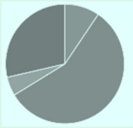


Figure 16. Topsoil SOC concentration using the 3-year rolling mean to minimise seasonal effects (left) and the annual trends showing average SOC, upper (75%) and lower (25%) bands (right) for Lower Eyre Peninsula.

Eastern Eyre Peninsula

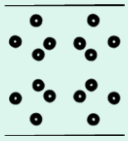
Key Land Use



Cropping: 95%

Pasture: 5%

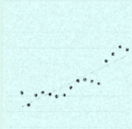
Mean SOC Conc



Ag District: 0.97 %

SA Ag Zone: 1.77%

Annual change SOC



Mean: 0.0157% ↑

25th: 0.01% 75th: 0.02%

Texture

Table 18. Benchmark topsoil SOC (%) values for texture displaying the mean and percentile values for Eastern Eyre Peninsula compared to the mean for the Agricultural Zone.

	Ag Zone			Ag District Benchmarks				
Texture	**Mean**	**Count**	**Mean**	**25%**	**40%**	**50%**	**60%**	**75%**
Sand	1.12							
Loamy sand	1.42	351	0.72	0.54	0.62	0.67	0.74	0.86
Sandy loam	1.79	429	0.88	0.63	0.77	0.82	0.90	1.07
Loam	1.96	371	1.05	0.80	0.94	1.03	1.13	1.27
Clay loam	1.93	310	1.21	0.91	1.09	1.16	1.24	1.46
Clay	1.66	312	1.04	0.70	0.90	1.00	1.10	1.28
Weighted Mean (all texture)	1.77	1773	0.97	0.71	0.85	0.92	1.01	1.17

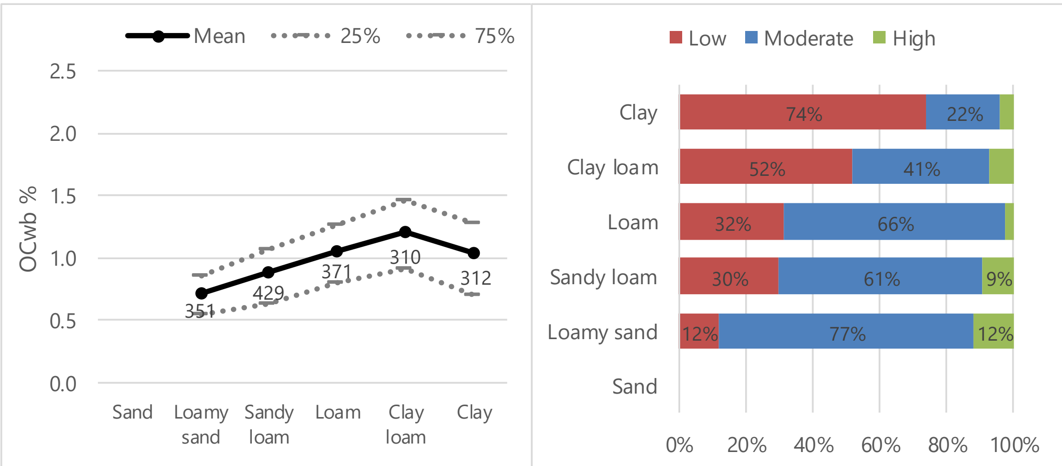


Figure 17. Eastern Eyre Peninsula topsoil average SOC %, number of samples, upper (75%) and lower (25%) bands (left) and proportion of texture samples in the high, moderate and low SOC range (right) for texture.

Land use

Table 19. Benchmark topsoil SOC (%) values for land use displaying the mean and percentile values and proportion of land use samples in the high, moderate and low SOC range (right) for Eastern Eyre Peninsula.

	Benchmark SOC Concentration					Proportion in SOC range			
Land use	**Count**	**Mean**	**25%**	**50%**	**75%**	**District Prop (%)**	**Low**	**Moderate**	**High**
Cropping	1180	0.98	0.71	0.93	1.2	95	27%	64%	9%
Pasture	58	1.18	0.77	1.05	1.45	5	36%	46%	18%

Change over time

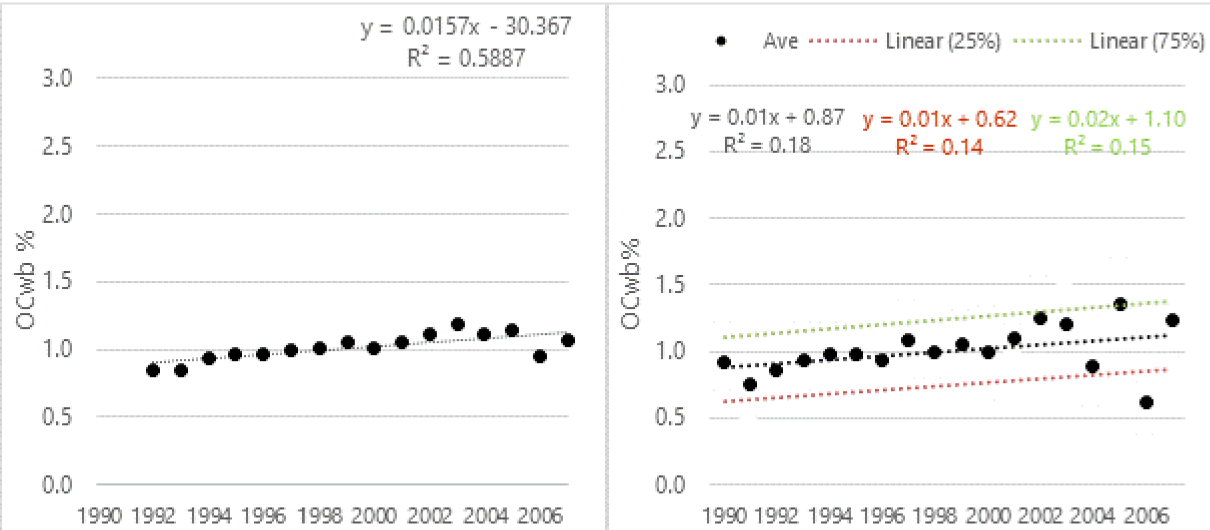
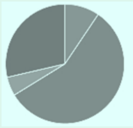


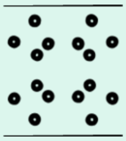
Figure 18. Topsoil SOC concentration using the 3-year rolling mean to minimise seasonal effects (left) and the annual trends showing average SOC, upper (75%) and lower (25%) bands (right) for Eastern Eyre Peninsula.

Western Eyre Peninsula

Key Land Use 

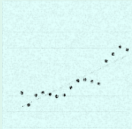
Cropping: 99%

Pasture: 1%

Mean SOC Conc 

Ag District: 1.12 %

SA Ag Zone: 1.77%

Annual change SOC 

Mean: 0.0411% ↑

25th: 0.03% 75th: 0.06%

Texture

Table 20. Benchmark topsoil SOC (%) values for texture displaying the mean and percentile values for Western Eyre Peninsula compared to the mean for the Agricultural Zone.

	Ag Zone	Ag District Benchmarks						
Texture	**Mean**	**Count**	**Mean**	**25%**	**40%**	**50%**	**60%**	**75%**
Sand	1.12	6	0.67	0.44	0.55	0.63	0.71	0.82
Loamy sand	1.42	372	1.01	0.67	0.80	0.89	1.06	1.28
Sandy loam	1.79	670	1.10	0.79	0.94	1.01	1.12	1.32
Loam	1.96	347	1.26	0.93	1.04	1.12	1.22	1.49
Clay loam	1.93	169	1.27	0.98	1.16	1.25	1.35	1.51
Clay	1.66	126	0.99	0.80	0.83	0.90	1.00	1.20
Weighted Mean (all texture)	1.77	1690	1.12	0.81	0.94	1.02	1.14	1.35

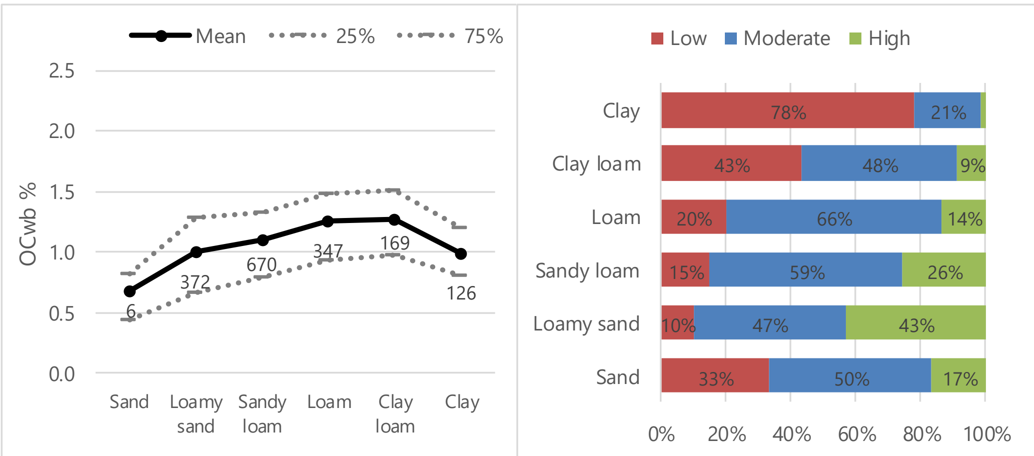


Figure 19. Western Eyre Peninsula topsoil average SOC %, number of samples, upper (75%) and lower (25%) bands (left) and proportion of texture samples in the high, moderate and low SOC range (right) for texture.

Land use

Table 21. Benchmark topsoil SOC (%) values for land use displaying the mean and percentile values and proportion of land use samples in the high, moderate and low SOC range (right) for Western Eyre Peninsula.

	Benchmark SOC Concentration					Proportion in SOC range			
Land use	Count	Mean	25%	50%	75%	District Prop (%)	Low	Moderate	High
Cropping	1261	1.16	0.81	1.09	1.41	99	15%	56%	29%
Pasture	15	1.14	0.63	0.94	1.63	1	29%	43%	29%

Change over time

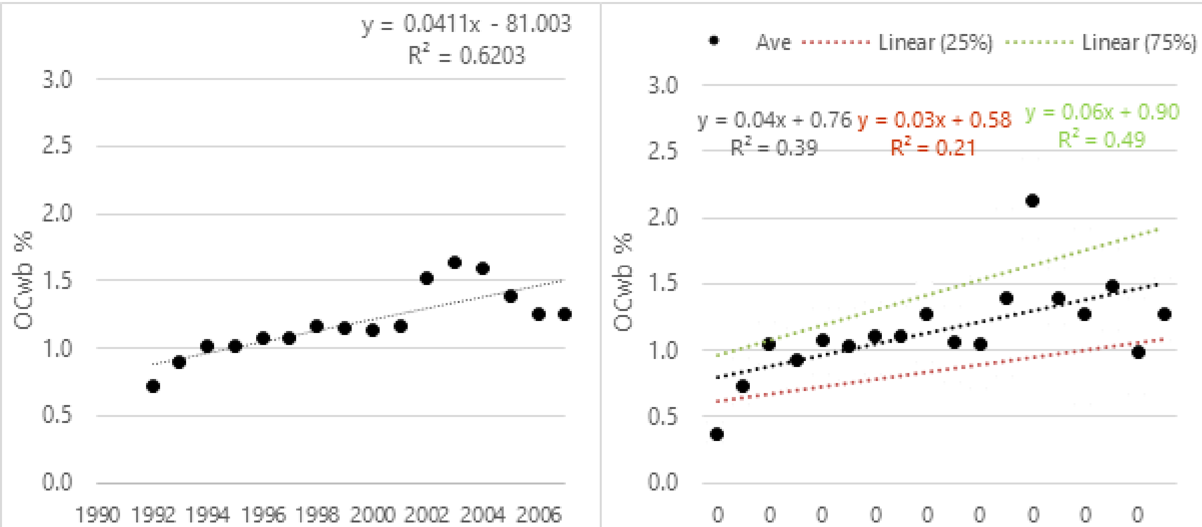
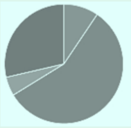
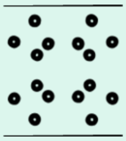
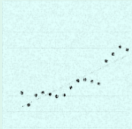


Figure 20. Topsoil SOC concentration using the 3-year rolling mean to minimise seasonal effects (left) and the annual trends showing average SOC, upper (75%) and lower (25%) bands (right) for Western Eyre Peninsula.

Lower North

Key Land Use 	Mean SOC Conc 	Annual change SOC 
Cropping: 47%	Ag District: 1.32 %	Mean: 0.0105% ↑
Orchard/Vineyard: 26%	SA Ag Zone: 1.77%	25th: 0.03% 75th: 0.03%

Texture

Table 22. Benchmark topsoil SOC (%) values for texture displaying the mean and percentile values for Lower North compared to the mean for the Agricultural Zone.

	Ag Zone	Ag District Benchmarks						
Texture	**Mean**	**Count**	**Mean**	**25%**	**40%**	**50%**	**60%**	**75%**
Sand	1.12							
Loamy sand	1.42	171	1.06	0.51	0.70	0.90	1.06	1.35
Sandy loam	1.79	395	1.20	0.74	0.96	1.08	1.28	1.56
Loam	1.96	603	1.37	0.90	1.11	1.20	1.36	1.64
Clay loam	1.93	1089	1.43	1.04	1.29	1.42	1.52	1.74
Clay	1.66	682	1.28	0.81	1.13	1.30	1.40	1.61
Weighted Mean (all texture)	1.77	2940	1.32	0.89	1.14	1.27	1.40	1.64

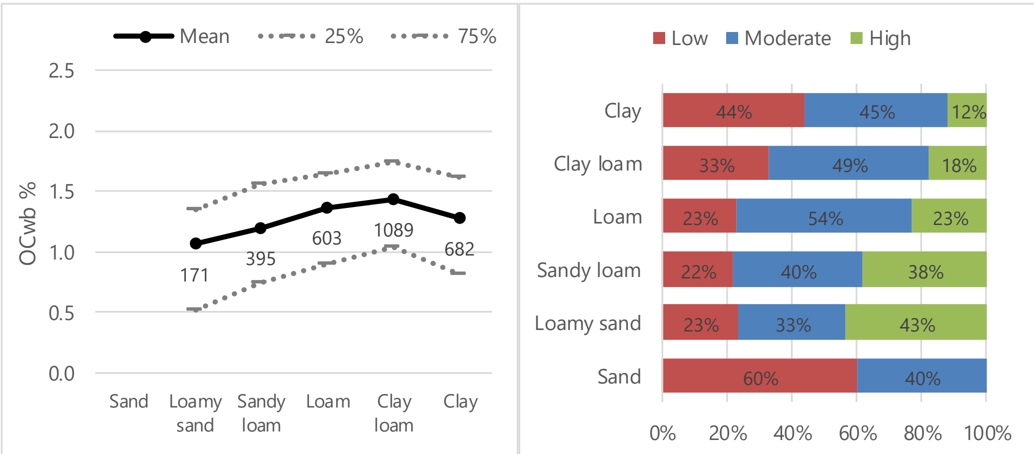


Figure 21. Lower North topsoil average SOC %, number of samples, upper (75%) and lower (25%) bands (left) and proportion of texture samples in the high, moderate and low SOC range (right) for texture.

Land use

Table 23. Benchmark topsoil SOC (%) values for land use displaying the mean and percentile values and proportion of land use samples in the high, moderate and low SOC range (right) for Lower North.

	Benchmark SOC Concentration					Proportion in SOC range			
Land use	Count	Mean	25%	50%	75%	District Prop (%)	Low	Moderate	High
Flowers	32	0.94	0.67	0.87	1.10	2	44%	44%	11%
Orchard / Vineyard	532	1.03	0.62	0.89	1.32	26	54%	34%	12%
Vegetable	151	1.28	0.76	1.18	1.70	7	43%	35%	22%
Cropping	973	1.50	1.20	1.48	1.74	47	13%	64%	23%
Forestry	31	1.65	0.90	1.42	2.18	1	26%	42%	32%
Pasture	357	1.75	1.26	1.71	2.17	17	11%	35%	53%

- Greater than 30% of samples in low SOC range for horticultural crops.
- Lower than expected cropping proportion may affect the average SOC values.

Change over time

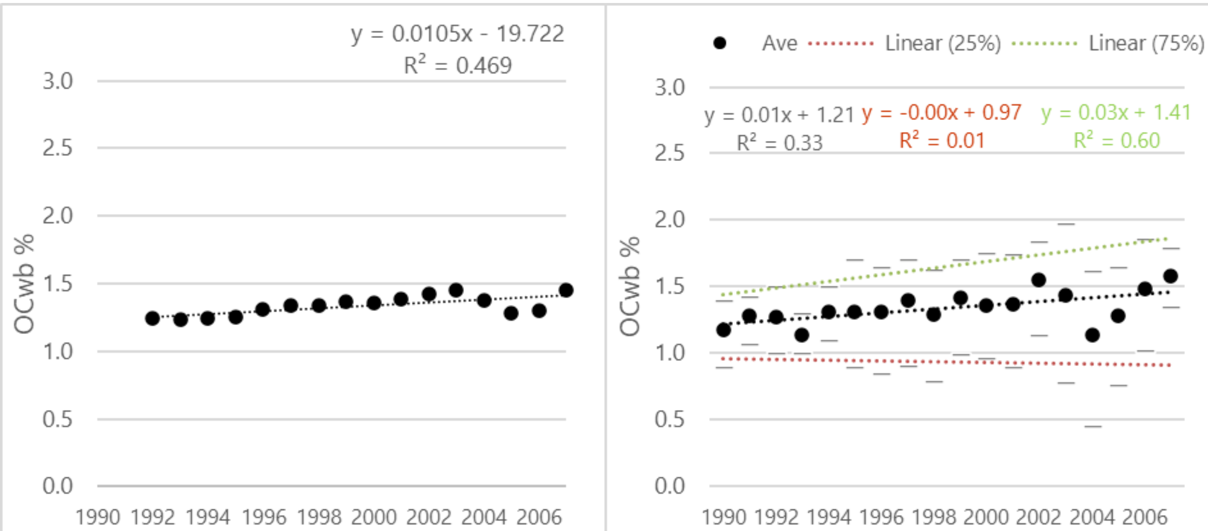
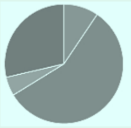


Figure 22. Topsoil SOC concentration using the 3-year rolling mean to minimise seasonal effects (left) and the annual trends showing average SOC upper (75%) and lower (25%) bands (right) for Lower North.

Mid North

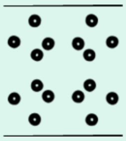
Key Land Use



Cropping: 82%

Orchard/Vineyard: 10%

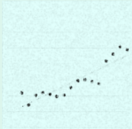
Mean SOC Conc



Ag District: 1.45 %

SA Ag Zone: 1.77%

Annual change SOC



Mean: 0.0349% ↑

25th: 0.03% 75th: 0.05%

Texture

Table 24. Benchmark topsoil SOC (%) values for texture displaying the mean and percentile values for Mid North compared to the mean for the Agricultural Zone.

	Ag Zone	Ag District Benchmarks						
Texture	**Mean**	**Count**	**Mean**	**25%**	**40%**	**50%**	**60%**	**75%**
Sand	1.12							
Loamy sand	1.42	41	0.78	0.51	0.62	0.66	0.85	1.00
Sandy loam	1.79	188	1.25	0.85	1.09	1.21	1.33	1.57
Loam	1.96	539	1.45	1.10	1.27	1.40	1.50	1.70
Clay loam	1.93	1346	1.50	1.18	1.33	1.45	1.54	1.71
Clay	1.66	1005	1.46	1.10	1.30	1.40	1.50	1.72
Weighted Mean (all texture)	1.77	3119	1.45	1.11	1.29	1.40	1.50	1.69

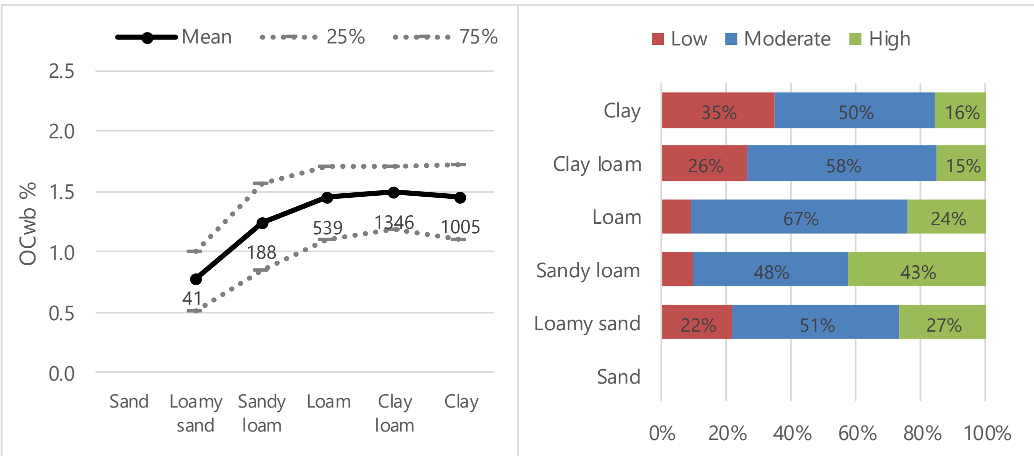


Figure 23. Mid North topsoil average SOC %, number of samples, upper (75%) and lower (25%) bands (left) and proportion of texture samples in the high, moderate and low SOC range (right) for texture.

Land use

Table 25. Benchmark topsoil SOC (%) values for land use displaying the mean and percentile values and proportion of land use samples in the high, moderate and low SOC range (right) for the Mid North.

	Benchmark SOC Concentration					Proportion in SOC range			
Land use	Count	Mean	25%	50%	75%	District Prop (%)	Low	Moderate	High
Orchard / Vineyard	192	1.32	0.82	1.31	1.69	10	37%	43%	20%
Cropping	1649	1.45	1.14	1.41	1.70	82	20%	61%	19%
Pasture	144	1.76	1.27	1.59	2.07	7	14%	51%	35%

Change over time

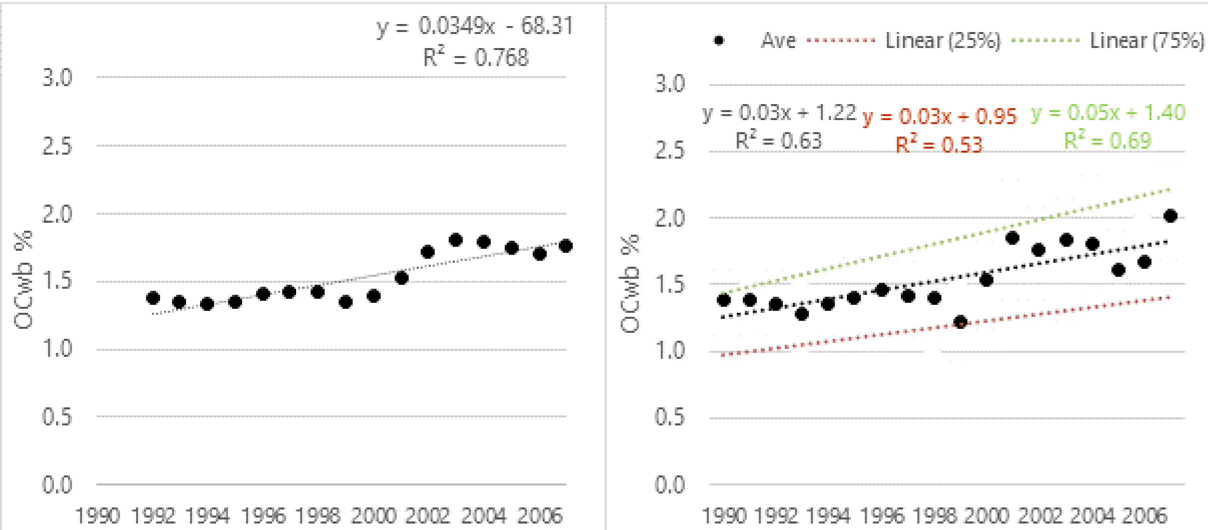
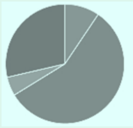


Figure 24. Topsoil SOC concentration using the 3-year rolling mean to minimise seasonal effects (left) and the annual trends showing average SOC, upper (75%) and lower (25%) bands (right) for the Mid North.

Upper North

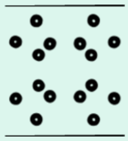
Key Land Use



Cropping: 90%

Pasture: 7%

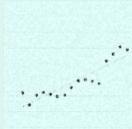
Mean SOC Conc



Ag District: 1.25 %

SA Ag Zone: 1.77%

Annual change SOC



Mean: 0.0352% ↑

25th: 0.03% 75th: 0.05%

Texture

Table 26. Benchmark topsoil SOC (%) values for texture displaying the mean and percentile values for Upper North compared to the mean for the Agricultural Zone.

	Ag Zone	Ag District Benchmarks						
Texture	**Mean**	**Count**	**Mean**	**25%**	**40%**	**50%**	**60%**	**75%**
Sand	1.12							
Loamy sand	1.42	29	0.62	0.49	0.51	0.53	0.54	0.64
Sandy loam	1.79	135	1.12	0.76	0.93	1.03	1.13	1.36
Loam	1.96	284	1.20	0.86	1.00	1.10	1.27	1.50
Clay loam	1.93	804	1.33	1.05	1.20	1.29	1.40	1.52
Clay	1.66	632	1.24	1.00	1.12	1.20	1.30	1.46
Weighted Mean (all texture)	1.77	1884	1.25	0.97	1.11	1.20	1.31	1.47

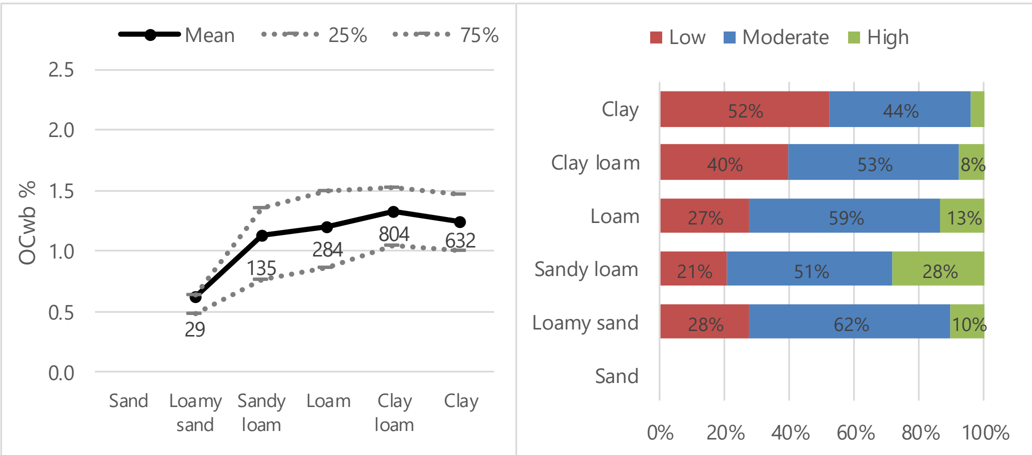


Figure 25. Upper North topsoil average SOC %, number of samples, upper (75%) and lower (25%) bands (left) and proportion of texture samples in the high, moderate and low SOC range (right) for texture.

Land use

Table 27. Benchmark topsoil SOC (%) values for land use displaying the mean and percentile values and proportion of land use samples in the high, moderate and low SOC range (right) for the Upper North.

	Benchmark SOC Concentration					Proportion in SOC range			
Land use	Count	Mean	25%	50%	75%	District Prop (%)	Low	Moderate	High
Cropping	192	1233	1.25	0.97	1.21	90	39%	51%	9%
Pasture	1649	94	1.33	0.90	1.27	7	37%	46%	18%
Orchard / Vineyard	144	34	1.46	0.87	1.36	2	29%	32%	38%

- Greater than 30% of samples in low SOC range for all land uses.

Change over time

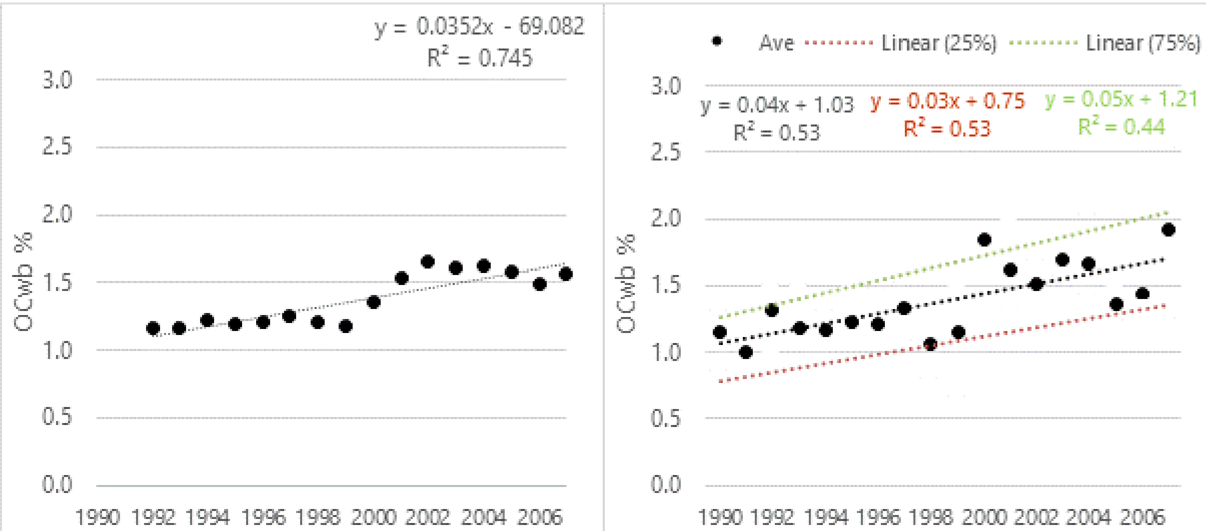
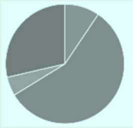


Figure 26. Topsoil SOC concentration using the 3-year rolling mean to minimise seasonal effects (left) and the annual trends showing average SOC, upper (75%) and lower (25%) bands (right) for the Upper North.

Yorke Peninsula

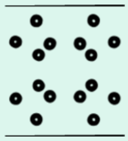
Key Land Use



Cropping: 90%

Pasture: 7%

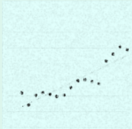
Mean SOC Conc



Ag District: 1.63 %

SA Ag Zone: 1.77%

Annual change SOC



Mean: 0.0692% ↑

25th: 0.04% 75th: 0.04%

Texture

Table 28. Benchmark topsoil SOC (%) values for texture displaying the mean and percentile values for the Yorke Peninsula compared to the mean for the Agricultural Zone.

	Ag Zone	Ag District Benchmarks						
Texture	**Mean**	**Count**	**Mean**	**25%**	**40%**	**50%**	**60%**	**75%**
Sand	1.12							
Loamy sand	1.42	168	1.06	0.77	0.86	0.95	1.01	1.26
Sandy loam	1.79	339	1.38	0.91	1.10	1.24	1.36	1.63
Loam	1.96	437	1.58	1.17	1.36	1.48	1.62	1.81
Clay loam	1.93	832	1.85	1.48	1.65	1.75	1.88	2.11
Clay	1.66	335	1.68	1.30	1.49	1.60	1.76	1.98
Weighted Mean (all texture)	1.77	2111	1.63	1.24	1.41	1.52	1.65	1.88

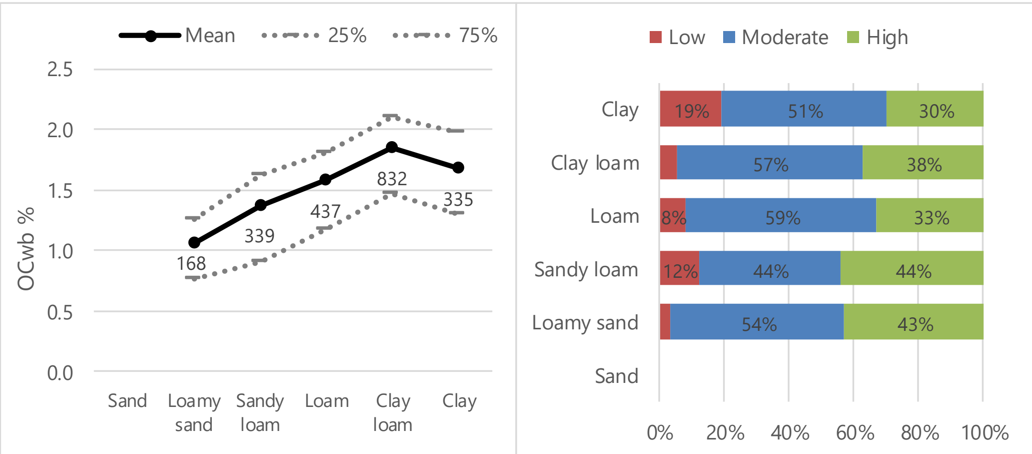


Figure 27. Yorke Peninsula topsoil average SOC %, number of samples, upper (75%) and lower (25%) bands (left) and proportion of texture samples in the high, moderate and low SOC range (right) for texture.

Land use

Table 29. Benchmark topsoil SOC (%) values for land use displaying the mean and percentile values and proportion of land use samples in the high, moderate and low SOC range (right) for the Yorke Peninsula.

	Benchmark SOC Concentration					Proportion in SOC range			
Land use	Count	Mean	25%	50%	75%	District Prop (%)	Low	Moderate	High
Cropping	1523	1.63	1.23	1.58	1.95	90	6%	55%	39%
Pasture	42	1.87	1.36	1.60	1.97	7	2%	66%	32%

- From 2000, there was an increasing proportion of soil test results in the high category.

Change over time

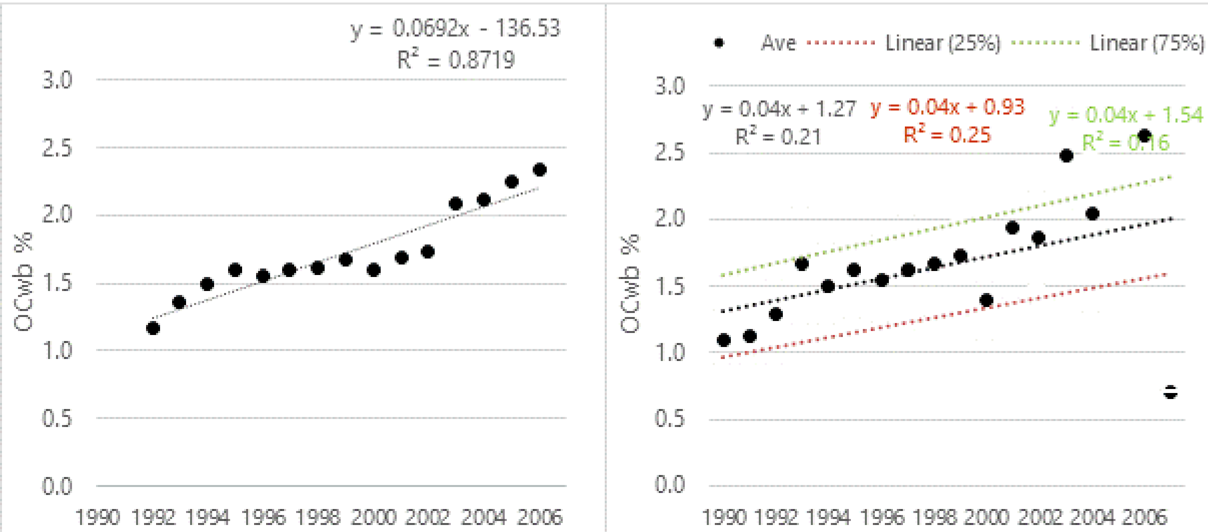
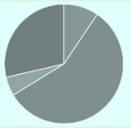


Figure 28. Topsoil SOC concentration using the 3-year rolling mean to minimise seasonal effects (left) and the annual trends showing average SOC, upper (75%) and lower (25%) bands (right) for the Yorke Peninsula.

Central Hills / Fleurieu Peninsula / Kangaroo Island (CH/FP/KI)

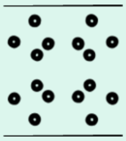
Key Land Use



Pasture: 63%

Orchard/Vineyard: 22%

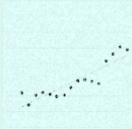
Mean SOC Conc



Ag District: 2.63 %

SA Ag Zone: 1.77%

Annual change SOC



Mean: 0.0678% ↑

25th: 0.03% 75th: 0.12%

Texture

Table 30. Benchmark topsoil SOC (%) values for texture displaying the mean and percentile values for the CH/FP/KI compared to the mean for the Agricultural Zone.

	Ag Zone	Ag District Benchmarks						
Texture	**Mean**	**Count**	**Mean**	**25%**	**40%**	**50%**	**60%**	**75%**
Sand	1.12	61	1.39	0.65	0.89	1.01	1.49	1.82
Loamy sand	1.42	1919	1.98	0.92	1.35	1.72	2.07	2.83
Sandy loam	1.79	2119	2.76	1.70	2.31	2.67	3.09	3.71
Loam	1.96	1939	2.96	1.84	2.56	2.94	3.28	3.93
Clay loam	1.93	2076	2.86	1.73	2.27	2.72	3.17	3.93
Clay	1.66	996	2.57	1.48	1.99	2.36	2.77	3.49
Weighted Mean (all texture)	1.77	9110	2.63	1.54	2.11	2.49	2.89	3.58

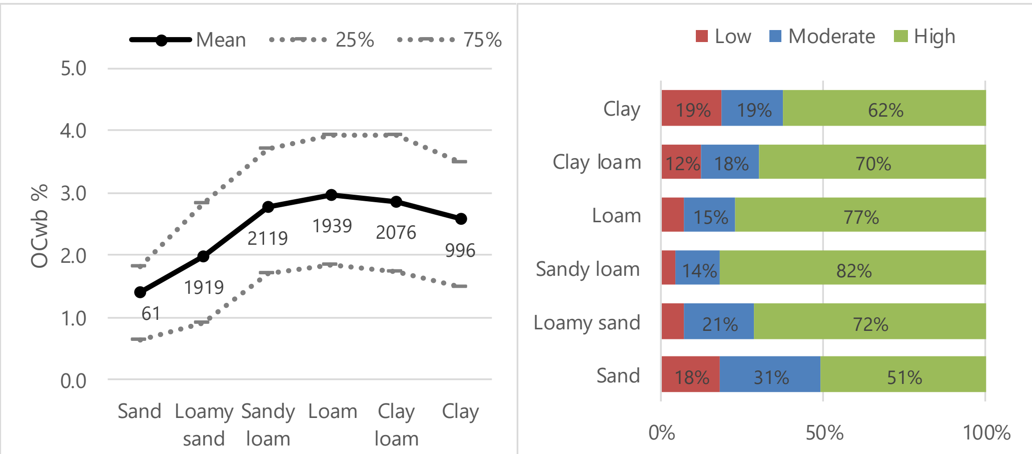


Figure 29. CH/FP/KI topsoil average SOC %, number of samples, upper (75%) and lower (25%) bands (left) and proportion of texture samples in the high, moderate and low SOC range (right) for texture.

Land use

Table 31. Benchmark topsoil SOC (%) values for land use displaying the mean and percentile values and proportion of land use samples in the high, moderate and low SOC range (right) for the CH/FP/KI.

	Benchmark SOC Concentration					Proportion in SOC range			
Land use	Count	Mean	25%	50%	75%	District Prop (%)	Low	Moderate	High
Orchard /Vineyard	1535	1.59	0.90	1.42	2.10	22	22%	37%	41%
Vegetable	204	1.88	0.97	1.67	2.22	3	10%	43%	47%
Cropping	603	2.15	1.20	1.83	2.84	9	5%	31%	65%
Flowers	59	2.20	1.63	2.32	2.73	1	14%	15%	71%
Forestry	80	2.60	1.26	2.39	3.70	1	9%	16%	75%
Irrigated pasture	88	3.01	2.19	3.08	3.80	1	7%	1%	92%
Pasture	4372	3.25	2.30	3.19	4.13	63	1%	5%	94%

- High proportion of soil test results in high category.

Change over time

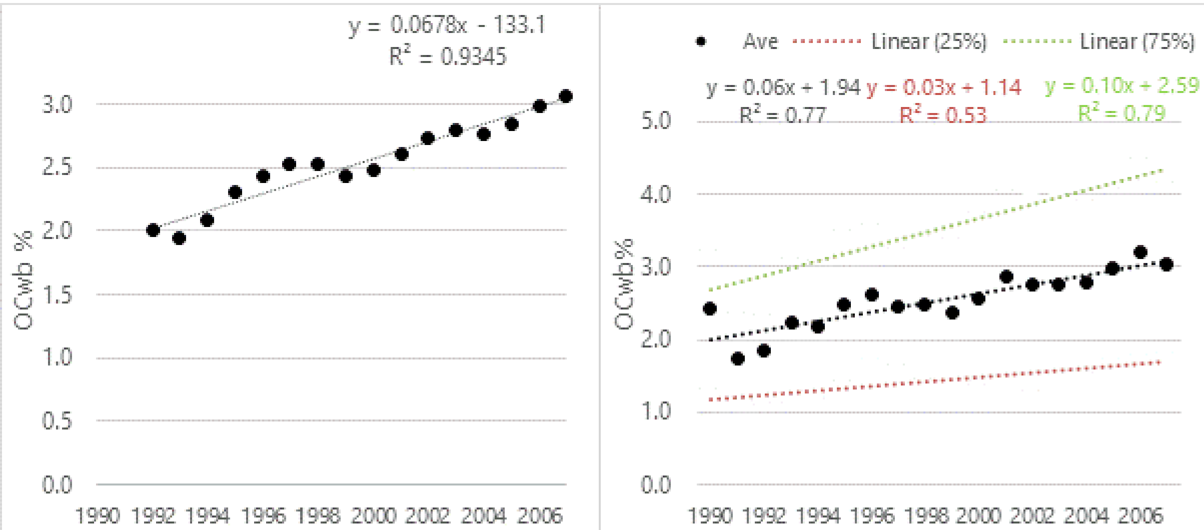
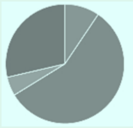


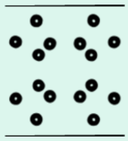
Figure 30. Topsoil SOC concentration using the 3-year rolling mean to minimise seasonal effects (left) and the annual trends showing average SOC, upper (75%) and lower (25%) bands (right) for the CH/FP/KI.

Lower Murray

Key Land Use 

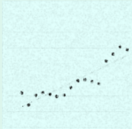
Cropping: 56%

Pasture: 28%

Mean SOC Conc 

Ag District: 1.45 %

SA Ag Zone: 1.77%

Annual change SOC 

Mean: 0.0685% ↑

25th: 0.00% 75th: 0.12%

Texture

Table 32. Benchmark topsoil SOC (%) values for texture displaying the mean and percentile values for the Lower Murray compared to the mean for the Agricultural Zone.

	Ag Zone	Ag District Benchmarks						
Texture	Mean	Count	Mean	25%	40%	50%	60%	75%
Sand	1.12							
Loamy sand	1.42	152	0.94	0.50	0.60	0.71	0.87	1.13
Sandy loam	1.79	172	1.40	0.79	1.03	1.18	1.32	1.80
Loam	1.96	159	1.47	0.89	1.10	1.21	1.40	1.73
Clay loam	1.93	145	1.66	1.10	1.29	1.40	1.56	1.86
Clay	1.66	81	2.10	1.10	1.33	1.51	1.77	2.34
Weighted Mean (all texture)	1.77	709	1.45	0.85	1.04	1.17	1.34	1.71

- No decrease in SOC for clay loam and clay as seen in other agricultural districts – possibly due to irrigation.

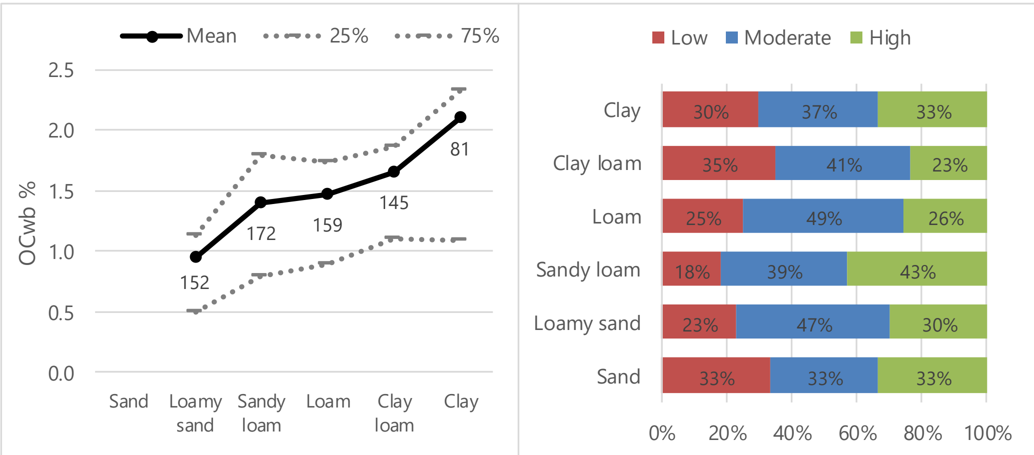


Figure 31. Lower Murray topsoil average SOC %, number of samples, upper (75%) and lower (25%) bands (left) and proportion of texture samples in the high, moderate and low SOC range (right) for texture.

Land use

Table 33. Benchmark topsoil SOC (%) values for land use displaying the mean and percentile values and proportion of land use samples in the high, moderate and low SOC range (right) for the Lower Murray.

	Benchmark SOC Concentration					Proportion in SOC range			
Land use	Count	Mean	25%	50%	75%	District Prop (%)	Low	Moderate	High
Orchard / Vineyard	48	1.02	0.44	0.88	1.36	9	52%	27%	21%
Cropping	288	1.19	0.80	1.18	1.46	56	27%	58%	16%
Vegetable	26	1.42	0.86	1.52	1.87	5	23%	31%	46%
Pasture	145	2.27	1.34	1.95	2.76	28	6%	27%	68%

Change over time

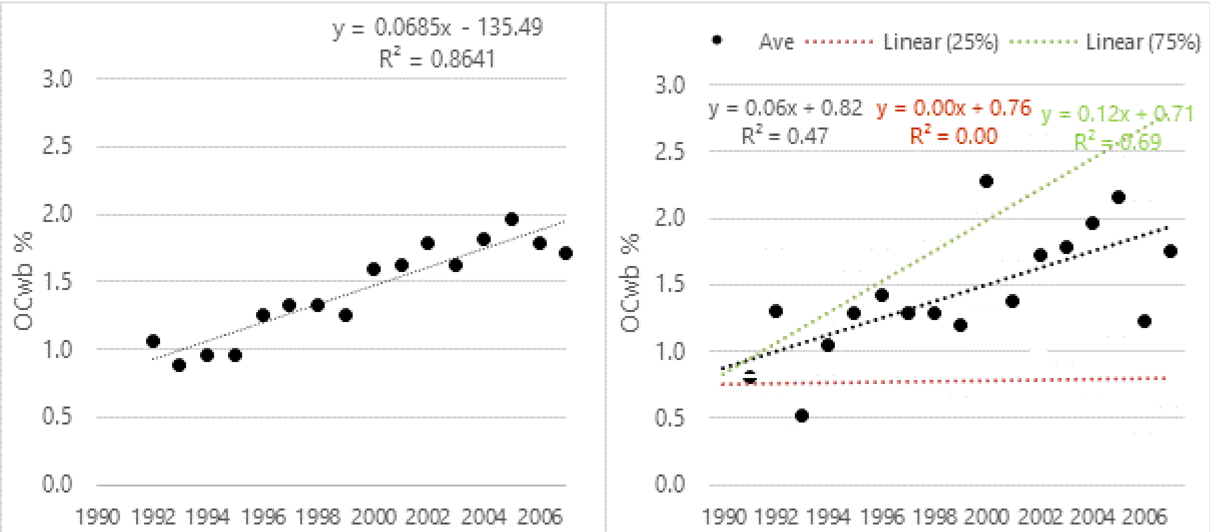
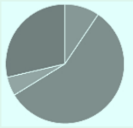
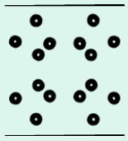
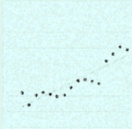


Figure 32. Topsoil SOC concentration using the 3-year rolling mean to minimise seasonal effects (left) and the annual trends showing average SOC, upper (75%) and lower (25%) bands (right) for the Lower Murray.

Southern Murray Mallee

Key Land Use	Mean SOC Conc	Annual change SOC
		
Cropping: 91%	Ag District: 0.75%	Mean: -0.0046% ↔
Pasture: 4%	SA Ag Zone: 1.77%	25th: -0.00% 75th: -0.00%

Texture

Table 34. Benchmark topsoil SOC (%) values for texture displaying the mean and percentile values for the Southern Murray Mallee compared to the mean for the Agricultural Zone.

	Ag Zone		Ag District Benchmarks					
Texture	**Mean**	**Count**	**Mean**	**25%**	**40%**	**50%**	**60%**	**75%**
Sand	1.12	11	0.65	0.51	0.54	0.57	0.60	0.73
Loamy sand	1.42	282	0.63	0.46	0.55	0.60	0.65	0.74
Sandy loam	1.79	156	0.80	0.60	0.70	0.73	0.80	0.93
Loam	1.96	103	0.90	0.70	0.80	0.80	0.90	1.01
Clay loam	1.93	28	1.04	0.81	0.97	1.00	1.02	1.14
Clay	1.66	12	1.03	0.85	0.90	0.90	0.90	1.10
Weighted Mean (all texture)	1.77	592	0.75	0.56	0.66	0.69	0.75	0.86

- No decrease in SOC for clay loam and clay as seen in other agricultural districts – possibly due to irrigation.

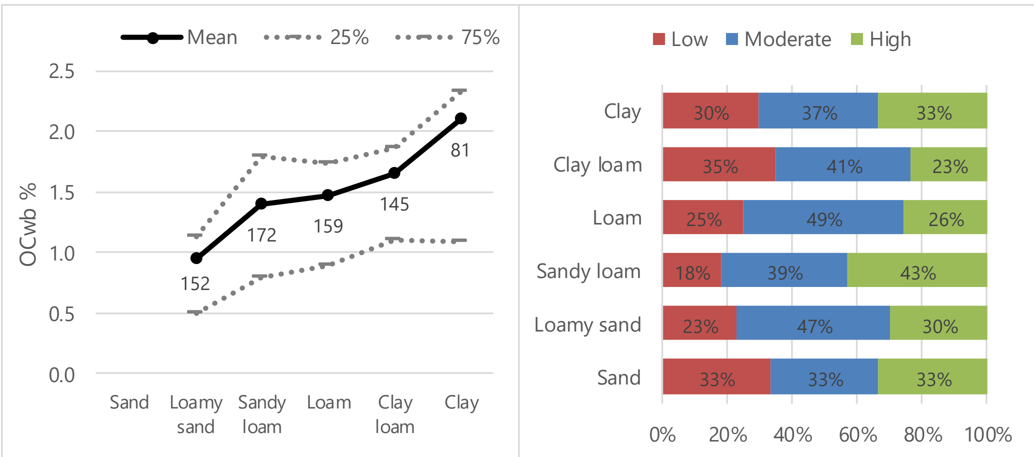


Figure 33. Southern Murray Mallee topsoil average SOC %, number of samples, upper (75%) and lower (25%) bands (left) and proportion of texture samples in the high, moderate and low SOC range (right) for texture.

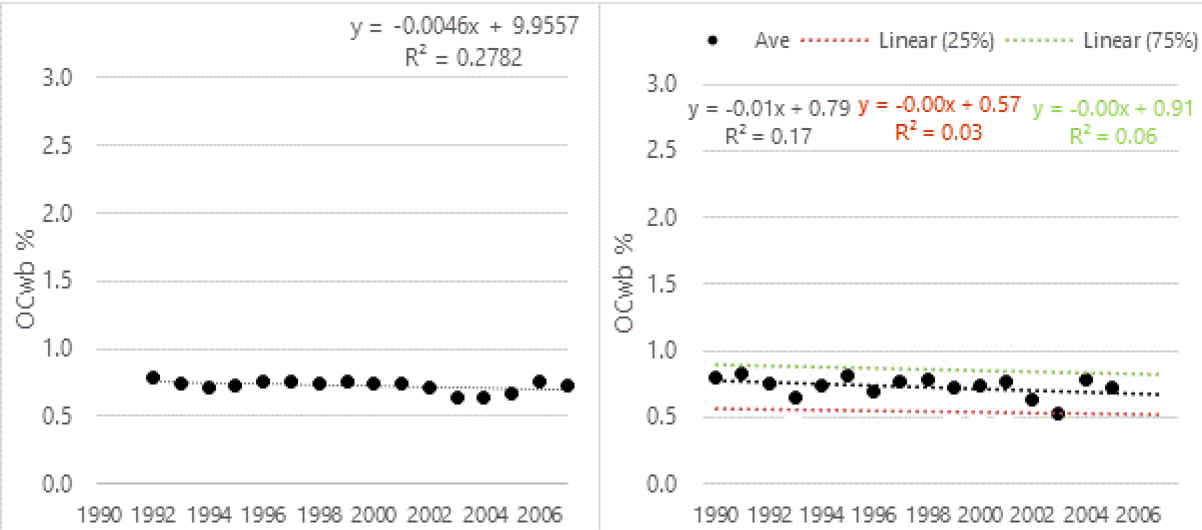
Land use

Table 35. Benchmark topsoil SOC (%) values for land use displaying the mean and percentile values and proportion of land use samples in the high, moderate and low SOC range (right) for the Southern Murray Mallee.

	Benchmark SOC Concentration					Proportion in SOC range			
Land use	**Count**	**Mean**	**25%**	**50%**	**75%**	**District Prop (%)**	**Low**	**Moderate**	**High**
Orchard /Vineyard	15	0.56	0.40	0.45	0.59	3	60%	40%	0%
Pasture	17	0.67	0.57	0.70	0.81	4	31%	63%	6%
Vegetable	10	0.67	0.51	0.60	0.80	2	50%	40%	10%
Cropping	419	0.76	0.55	0.70	0.93	91	34%	60%	6%

- Greater than 30% of samples in the low SOC range.

Change over time

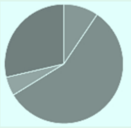


- There is a steady to declining trend of SOC concentration over time.

Figure 34. Topsoil SOC concentration using the 3-year rolling mean to minimise seasonal effects (left) and the annual trends showing average SOC, upper (75%) and lower (25%) bands (right) for the Southern Murray Mallee.

Northern Murray Mallee

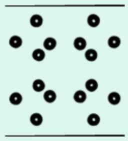
Key Land Use



Orchard /Vineyard: 46%

Cropping: 45%

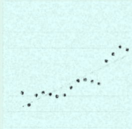
Mean SOC Conc



Ag District: 0.60%

SA Ag Zone: 1.77%

Annual change SOC



Mean: 0.0119% ↔

25th: - 0.00% 75th: 0.01%

Texture

Table 36. Benchmark topsoil SOC (%) values for texture displaying the mean and percentile values for the Northern Murray Mallee compared to the mean for the Agricultural Zone.

	Ag Zone		Ag District Benchmarks					
Texture	**Mean**	**Count**	**Mean**	**25%**	**40%**	**50%**	**60%**	**75%**
Sand	1.12	13	0.26	0.07	0.12	0.13	0.23	0.47
Loamy sand	1.42	236	0.48	0.34	0.40	0.45	0.48	0.55
Sandy loam	1.79	190	0.52	0.35	0.41	0.46	0.52	0.63
Loam	1.96	100	0.74	0.37	0.54	0.63	0.71	1.00
Clay loam	1.93	82	1.00	0.46	0.65	0.81	1.01	1.33
Clay	1.66	44	0.77	0.18	0.34	0.42	0.66	1.34
Weighted Mean (all texture)	1.77	665	0.60	0.35	0.44	0.51	0.60	0.79

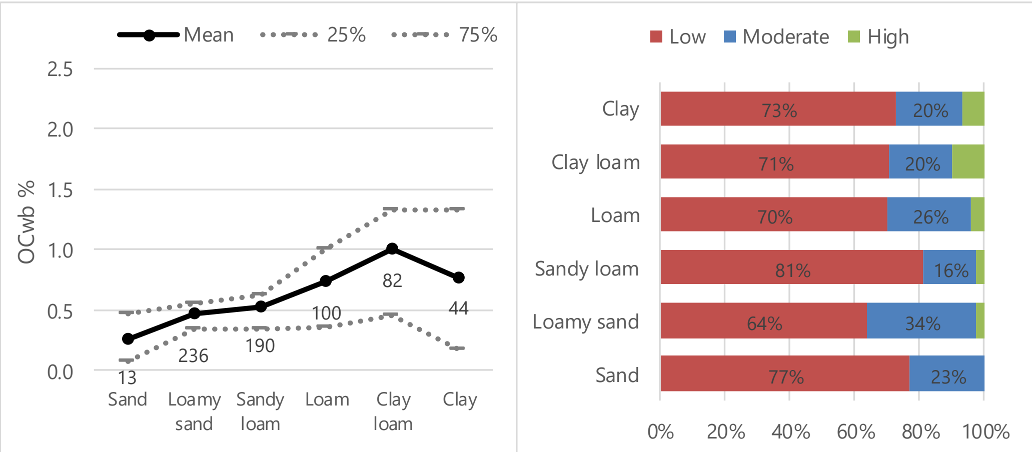


Figure 35. Northern Murray Mallee topsoil average SOC %, number of samples, upper (75%) and lower (25%) bands (left) and proportion of texture samples in the high, moderate and low SOC range (right) for texture.

Land use

Table 37. Benchmark topsoil SOC (%) values for land use displaying the mean and percentile values and proportion of land use samples in the high, moderate and low SOC range (right) for the Northern Murray Mallee.

	Benchmark SOC Concentration					Proportion in SOC range			
Land use	Count	Mean	25%	50%	75%	District Prop (%)	Low	Moderate	High
Cropping	191	0.58	0.40	0.50	0.65	45	77%	21%	3%
Orchard / Vineyard	199	0.56	0.33	0.46	0.67	46	64%	35%	1%
Pasture	34	0.58	0.40	0.50	0.70	8	75%	17%	8%

- Greater than 60% of samples in the low SOC range.

Change over time

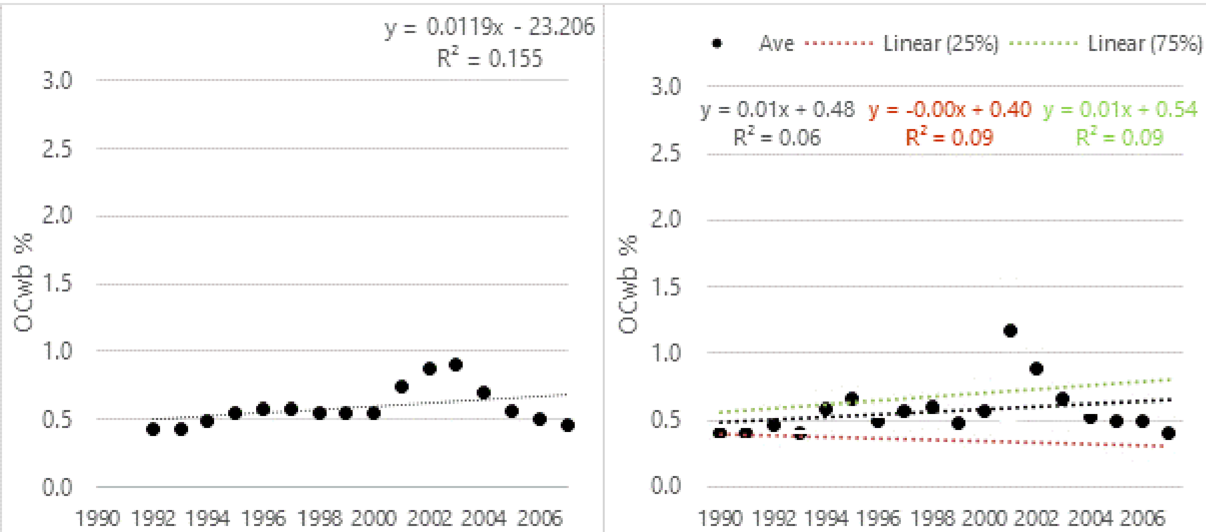
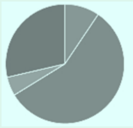


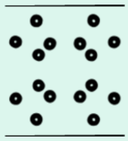
Figure 36. Topsoil SOC concentration using the 3-year rolling mean to minimise seasonal effects (left) and the annual trends showing average SOC, upper (75%) and lower (25%) bands (right) for the Northern Murray Mallee.

Lower South East

Key Land Use 

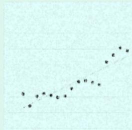
Pasture: 57%

Cropping: 28%

Mean SOC Conc 

Ag District: 2.47%

SA Ag Zone: 1.77%

Annual change SOC 

Mean: -0.0185% ↔

25th: - 0.02% 75th: -0.03%

Texture

Table 38. Benchmark topsoil SOC (%) values for texture displaying the mean and percentile values for the Lower South East compared to the mean for the Agricultural Zone.

	Ag Zone		Ag District Benchmarks					
Texture	**Mean**	**Count**	**Mean**	**25%**	**40%**	**50%**	**60%**	**75%**
Sand	1.12	13	1.65	1.29	1.45	1.52	1.57	1.75
Loamy sand	1.42	818	1.89	1.19	1.48	1.71	2.01	2.45
Sandy loam	1.79	502	2.38	1.48	1.87	2.07	2.40	3.05
Loam	1.96	374	2.93	1.80	2.35	2.71	3.12	3.91
Clay loam	1.93	526	2.97	1.61	2.32	3.13	3.56	4.11
Clay	1.66	262	2.81	1.31	2.10	2.59	3.20	4.10
Weighted Mean (all texture)	1.77	2495	2.47	1.44	1.93	2.32	2.70	3.31

- Around 20% of samples in low SOC range for clay loam and clay soils. Unexpected as highest rainfall.

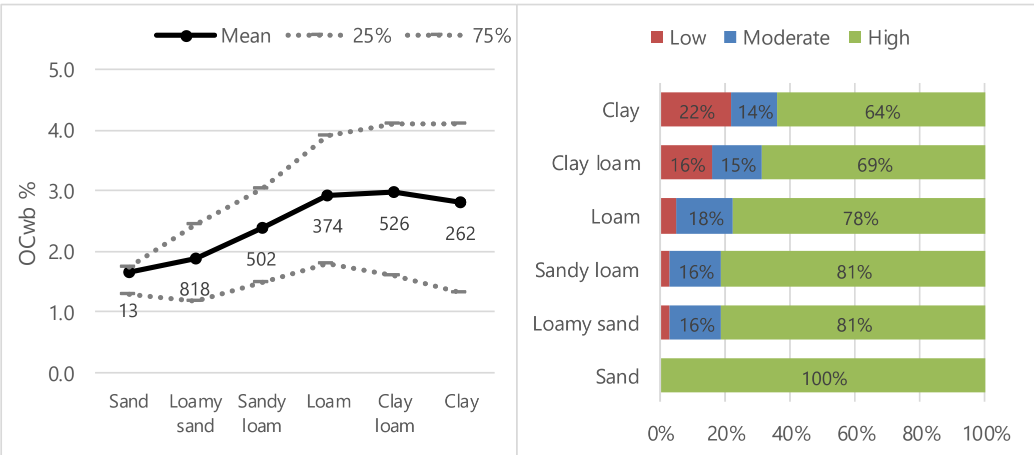


Figure 37. Lower South East topsoil average SOC %, number of samples, upper (75%) and lower (25%) bands (left) and proportion of texture samples in the high, moderate and low SOC range (right) for texture.

Land use

Table 39. Benchmark topsoil SOC (%) values for land use displaying the mean and percentile values and proportion of land use samples in the high, moderate and low SOC range (right) for the Lower South East.

	Benchmark SOC Concentration					Proportion in SOC range			
Land use	Count	Mean	25%	50%	75%	District Prop (%)	Low	Moderate	High
Orchard / Vineyard	274	1.40	0.83	1.21	1.83	15	37%	27%	36%
Vegetable	97	2.08	1.27	2.09	2.73	5	2%	20%	77%
Forestry	31	2.11	1.36	2.02	2.78	2	6%	13%	81%
Cropping	369	2.89	1.62	2.72	3.86	20	1%	12%	87%
Pasture	1046	2.86	1.81	2.59	3.80	57	1%	8%	91%
Irrigated Pasture	24	3.01	2.07	2.73	3.86	1	0%	5%	95%

- Greater than 30% of samples in low SOC range for orchard / vineyard but greater than 70% in high range for other land uses.

Change over time

The declining SOC trend over time is concerning for this district as it could indicate an increase rather than decrease in greenhouse gas emissions. The decline from 2004 onwards could be due to conversion of pasture to cropping or orchard/vineyard or may be caused by incorrect representation of land uses in the district and requires further investigation.

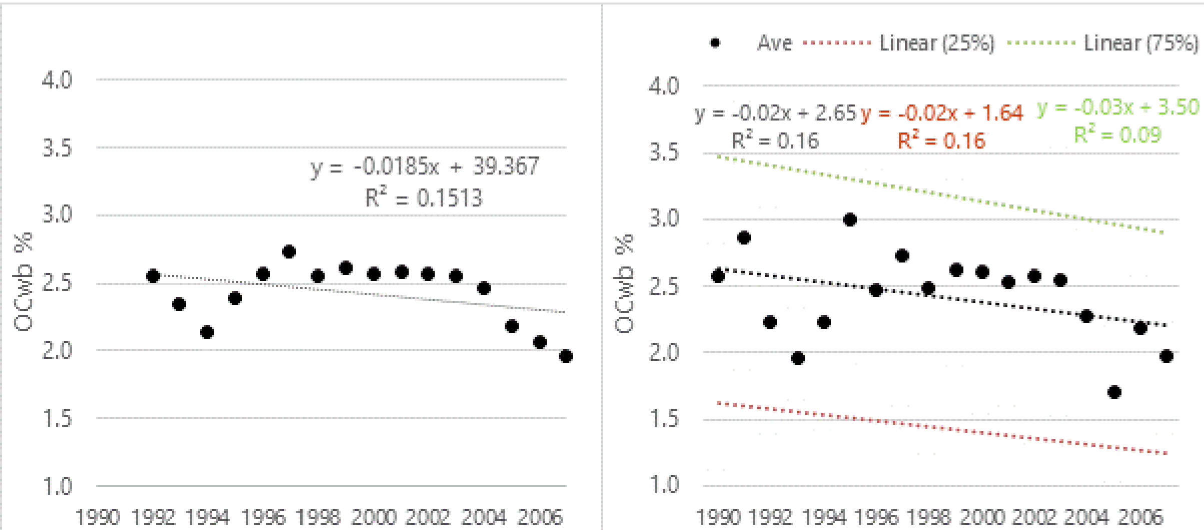
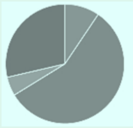


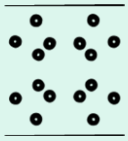
Figure 38. Topsoil SOC concentration using the 3-year rolling mean to minimise seasonal effects (left) and the annual trends showing average SOC, upper (75%) and lower (25%) bands (right) for the Lower South East.

Upper South East

Key Land Use 

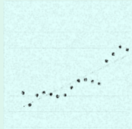
Cropping: 54%

Pasture: 31%

Mean SOC Conc 

Ag District: 1.45%

SA Ag Zone: 1.77%

Annual change SOC 

Mean: 0.0103% ↔

25th: 0.01% 75th: 0.03%

Texture

Table 40. Benchmark topsoil SOC (%) values for texture displaying the mean and percentile values for the Upper South East compared to the mean for the Agricultural Zone.

	Ag Zone	Ag District Benchmarks						
Texture	**Mean**	**Count**	**Mean**	**25%**	**40%**	**50%**	**60%**	**75%**
Sand	1.12	23	1.08	0.90	1.05	1.12	1.19	1.31
Loamy sand	1.42	933	1.21	0.85	1.01	1.10	1.24	1.51
Sandy loam	1.79	636	1.43	0.96	1.20	1.35	1.50	1.80
Loam	1.96	437	1.66	1.20	1.40	1.50	1.70	1.97
Clay loam	1.93	308	1.81	1.40	1.59	1.74	1.87	2.13
Clay	1.66	288	1.63	1.00	1.26	1.40	1.60	1.92
Weighted Mean (all texture)	1.77	2625	1.45	1.02	1.22	1.33	1.49	1.77

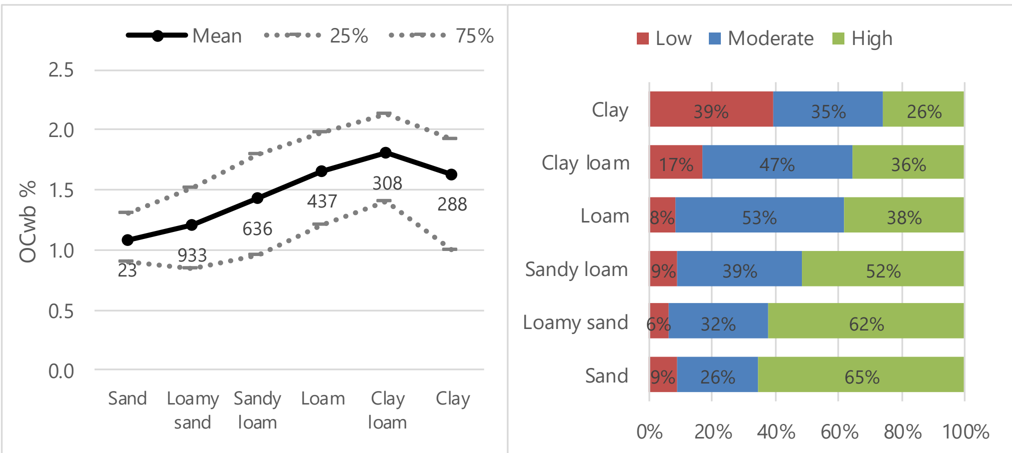


Figure 39. Upper South East topsoil average SOC %, number of samples, upper (75%) and lower (25%) bands (left) and proportion of texture samples in the high, moderate and low SOC range (right) for texture.

Land use

Table 41. Benchmark topsoil SOC (%) values for land use displaying the mean and percentile values and proportion of land use samples in the high, moderate and low SOC range (right) for the Upper South East.

	Benchmark SOC Concentration					Proportion in SOC range			
Land use	Count	Mean	25%	50%	75%	District Prop (%)	Low	Moderate	High
Orchard / Vineyard	235	0.98	0.58	0.87	1.30	12	60%	25%	15%
Cropping	1084	1.50	1.06	1.43	1.86	54	5%	40%	55%
Irrigated Pasture	20	1.54	1.10	1.41	1.86	1	0%	21%	79%
Pasture	620	1.55	1.00	1.36	1.91	31	7%	30%	63%
Vegetable	37	1.67	1.10	1.51	2.24	2	0%	54%	46%

- Greater than 60% of samples in low SOC range for orchard / vineyard but greater than 50% of samples in high SOC range for other land uses.

Change over time

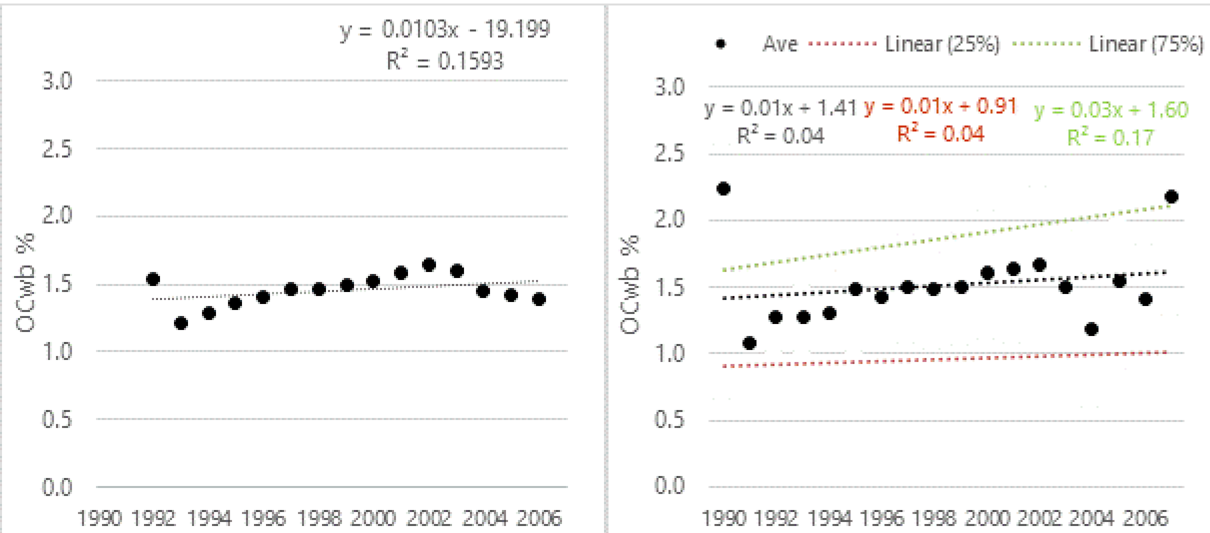


Figure 40. Topsoil SOC concentration using the 3-year rolling mean to minimise seasonal effects (left) and the annual trends showing average SOC, upper (75%) and lower (25%) bands (right) for the Upper South East.

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