Carbon sequestration in clay-modified soil

This research identified what factors increase carbon sequestration of clay-modified soils in South Australia. It will inform agricultural carbon offset policies and the objectives of increased soil productivity and net zero emissions

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Project partners:

Adding clay to the subsoil of sandy soils (clay modification) is a practice used in South Australia, Victoria and Western Australia to overcome soil water repellence and improve water retention, fertility and agricultural productivity.

Clay modification also has the potential to increase soil organic carbon (OC) storage through increased plant growth (above and below ground) and increased capacity to store and stabilise the new OC by binding to clay clods. This project was designed to understand whether clay modification could be optimised to increase OC storage, achieve further nitrogen emission abatement and provide more detailed estimates of clay-amended soils' potential to increase OC content.

The project involved a literature review and collation of available soil carbon data from 49 clay-modified sites and 49 unmodified sites across three South Australian regions: South East, Murray Mallee and Eyre Peninsula.

Sandy soils cover approximately 2.6 million hectares of South Australia's agricultural region and clay modification is used to increase soil water retention, fertility and plant productivity. Clay modification could also increase OC storage but there are no detailed estimates available on how clay-amended soils could increase OC content. Similarly, there is little information about whether clay-addition methods can be optimised to increase OC storage and achieve further nitrogen emission abatement.

A knowledge gap analysis was undertaken to better understand:

- the factors driving soil OC and the carbon sequestration potential of clay-modified soils
- the most suitable carbon and nitrogen models that can be applied to clay-modified soils
- what research is needed to support opportunities for carbon sequestration and nitrous oxide reduction in clay-modified soils.

KEY FINDINGS

- Adding subsoil clay to sandy topsoil increased soil organic carbon stock by 4–8 tha-1 compared to unmodified sandy soil in South Australia.
- Rainfall, clay concentration and depth to sub-soil clay were among the important factors and processes that can maximise OC stock in clay modified soils. The team used this research to develop a conceptual model of the theoretical factors that influence soil organic carbon.
- OC opportunity differed between theoretical estimates from previous state government studies and measured field data collated for this project. This suggests that either the theoretical data over-estimated OC stock potential or there are limitations to achieving OC potential. Sampling soils under 'best practice' management will help test the assumptions used in the theoretical estimates.
- Further research is required to develop guidelines for clay-modification techniques for soil carbon sequestration in South Australia, in particular a greater understanding of the range of carbon stocks for a given soil, of a known clay concentration within a particular rainfall zone.

IMPACT

These findings will help inform agricultural carbon offset policy, identify the next steps needed to develop a carbon offsets and emission program specific to clay-modified soils in South Australia, and help develop appropriate guidelines for growers and landholders.

WHAT FACTORS DRIVE SOIL OC AND CARBON STORAGE POTENTIAL?

Data from existing studies on clay-modified and unmodified field sites across South Australia was collated and analysed to identify driving factors and practices that help realise soil OC potential and their effect on OC stock in clay-modified soil. In particular, clay modification was found to increase SOC stock in the surface 30 cm of soil by an average 4.9 t/ha-1, with a 4–8 t/ha-1 range depending on rainfall zone.

Rainfall, clay concentration, and soil type (depth to subsoil clay) directly affected the soil OC stock threshold in clay-modified soils.

Clay clod distribution (depth of incorporation and clay source), clay clod size, nutrient application, and farming system improved the probability of creating a clay-modified soil that can reach its OC threshold.

Driving factors and practice options that help realise soil OC potential and their effect on OC stock in clay-modified soil.

Arrows pointing up indicate an increase and arrows pointing down indicate a decrease. The number of arrows indicates the

Factor	Effect on OC Stock	Confidence	Comment
An increase in factor that directly affects OC stock threshold			
Rainfall / Water storage	↑↑	***	Determines the amount of biomass that can be grown
Temperature/Evaporation	↓	***	Negative correlation – effect on soil microbes and plant physiology
Clay concentration	↑↑	***	Positive correlation to an upper limit of 20% clay. Minimal difference in OC stock between modified and unmodified soil where clay > 20% in 0-30 cm. Related to soil where subsoil clay within 30 cm (see below)
Depth to subsoil clay / soil type	↑	**	Clay modification best on sandy soil with > 30-40 cm to subsoil clay (texture contrast soil). Greatest stock increase where subsoil clay > 70 cm (deep sand). Minimal difference in OC stock at depth < 30 cm (shallow texture contrast soil).
An increase in practice options that can realise the OC stock threshold			
Clay clod size	?	*	This study has no sites with OC data by clod size. However, other studies have demonstrated a negative correlation for OC concentration (Schapel *et al.* 2018 in press).
Depth of incorporation	↑	**	Deep incorporation (to 30 cm) is important where subsoil clay > 60 cm. Incorporating clay clods to 30 cm increases OC stock of the 10—30 cm depth when compared to unmodified soil.
Nutrient application	↑↑	**	Increased nutrition increases plant biomass = increased OM input into the soil. May also provide nutrients for microbes to cycle OM, that could in turn affect OC fractions
Time since modification	↑↓	**	Positive correlation to 10 years post modification for rainfall zones < 450 mm. Negative correlation for rainfall > 500 mm but this is due to changes in clay modification practices over time where younger sites have higher OC stock compared to older sites > 25 years
Addition of organic matter	-?	*	Unable to determine the effect of OM addition in this study. Addition of OM has been shown elsewhere to increase biomass production and hence OC concentration. However, it is unknown how increased microbial activity affects OC concentration. The addition of clay should provide greater protection to OC from microbial decomposition compared to sand alone.

The key factors or practices that influence carbon stock across rainfall zones. Number of ticks indicates the level of influence on OC stock.

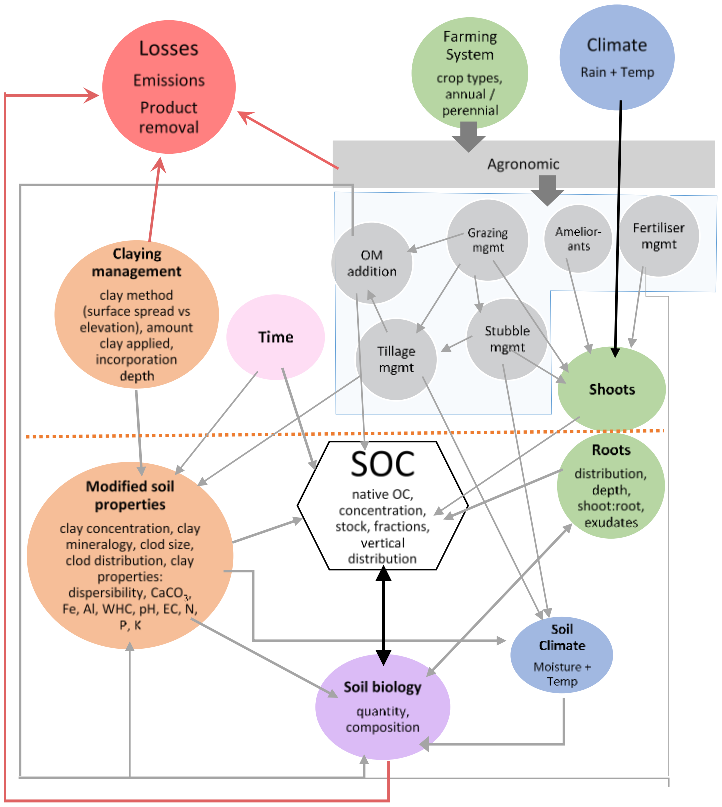
	350-400 mm	400-450 mm	450-500 mm	>500 mm
Rainfall / Water storage	✓✓✓	✓✓✓	✓	
Clay concentration		✓✓	✓✓✓	
Time since modification				✓
Nutrition	✓		✓✓✓	
Depth to subsoil clay / soil type	✓✓	✓✓	✓✓	✓
Limiting factor	**Inputs (above ground)**		**Outputs (below ground)**	

Previous state government studies have estimated the theoretical OC stock opportunity of clay-modified soils based on 'best practice' clay modification with few limitations to increasing OC stock. The opposite is true for the measured field data collated for this project. The researchers identified a difference in OC opportunity between the theoretical and measured data. This suggests that either the theoretical data over-estimated OC stock potential or the measured data indicates that there could be limitations to achieving OC potential. Investigating the OC stock opportunity by refining the measured dataset to sites that have had 'best practice' management could help answer this question.

A CONCEPTUAL SOIL ORGANIC CARBON MODEL

The research team also developed a conceptual model outlining the theoretical factors that influence soil organic carbon (SOC), including those specific to clay modification (coloured brown).

Abbreviations:
mgmt. - management
OM - organic matter
D - delving
CS - clay spreading
temp – temperature
CaCO3 – calcium carbonate
Fe – iron
Al – aluminium
WHC – water holding capacity
EC – electrical conductivity
N – nitrogen
P – phosphorous
K – potassium



WHAT MODELS CAN WE USE TO WORK OUT CHANGES TO SOIL ORGANIC CARBON STOCKS AND NITROGEN EMISSIONS AFTER ADDING CLAY?

The project tested a number of soil organic matter (SOM) simulation models to see which best represented the changes in soil OC stocks and nitrogen emissions after clay modification.

- **FullCAM model** – This is used by the National Carbon Accounting System to model carbon stock change and emissions. While providing realistic modelling of soil OC levels in clay-modified soils, FullCAM has some limitations in that it is fairly insensitive to the amount of clay in the soil as it assumes that clay content is distributed evenly within the soil rather than in clods as occurs in clay-modified soil. Predictions in OC stock changes after clay modification may be impacted.
- **HYDRUS model** – Water balance modelling with HYDRUS highlighted the importance of understanding the interaction between clay clod size and distribution, the impact of the nature of connected flowpaths on the migration of solutes and the impact on plant growth and yield. Further research is needed to understand the impact of connected flowpaths on the migration of solutes (e.g. fertilisers or pesticides) within the soil profile and whether clod size affects the efficacy of such agrochemicals.
- **Nitrous oxide calculators** – Two nitrous oxide emission calculators were compared against real-time data from two properties on Eyre Peninsula. These indicated that calculated emissions are similar to those measured in real-time. However, further comparison between calculators and real-time emissions measurement is recommended before final conclusions can be drawn.

NEXT STEPS

A series of knowledge gaps were identified that need to be filled before we can develop guidelines for soil carbon sequestration using clay modification techniques in South Australia.

1. Measure key parameters that have been identified as missing or inadequate in models (FullCAM, APSIM, HYDRUS and PHREEQC)
2. Use models to gain greater understanding of how to improve carbon sequestration and verify outputs of models with targeted field sampling and laboratory experiments
3. Identify rainfall zones and practices where clay modification has the greatest potential to increase OC
4. Overcome barriers to landholders entering into ERF soil carbon projects

MORE INFORMATION

The following technical report associated with the research program is located at www.goyderinstitute.org/publications/technical-reports/:

- Schapel, A., Reseigh, J., Wurst, M., Mallants, D. and Herrmann, T. (2018) Offsetting greenhouse gas emissions through increasing soil organic carbon in SA clay-modified soils: knowledge gap analysis. Goyder Institute for Water Research Technical Report Series No. 18/05, Adelaide, South Australia

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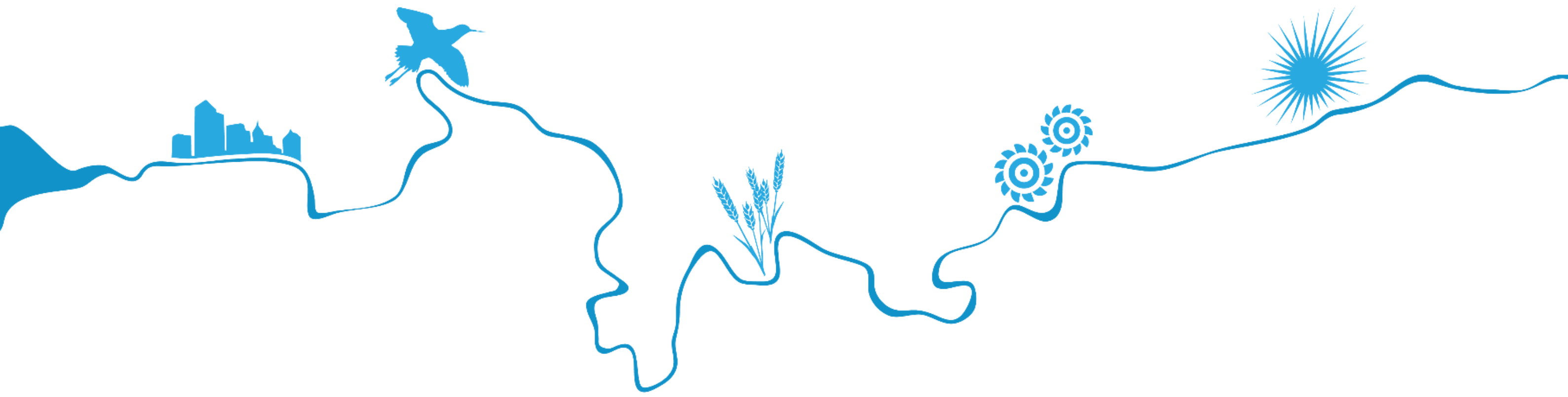

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