ReCon Soil - Reconstructed Soils from Waste

FACTSHEET

– Carbon Storage Potential of ReCon Soil Constructed Soils

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Overview

This factsheet provides the carbon storage data for three ReCon Soil constructed soils. The carbon storage potentials of these soils have been benchmarked against native 'natural' soils.

ReCon Soil constructed soils

Three ReCon Soil recipes were assessed (their key properties are provided in Appendix A). These were:

1) ***E1Ss*** constructed from UK green waste compost (UK GWC; 32.5%), composted bark (CB; 32.5%), sharp sand (SS; 25%) and lignite clay (LC; 10%) (Figure 1.1); this soil recipe was created by University of Plymouth, UK and Eden Project Learning, UK.
2) ***E2Bc*** constructed from compost like output agricultural residues (CLO AR; 24.5%), 20mm screened topsoil (STS; 24.5%), Greenworld green waste compost (GW GWC; 24.5%), sub soil peat (SSP; 24.5%) and factor X-charcoal dust/biochar (FXBC; 2%) (Figure 1.2); this soil recipe was created by Greenword Ltd, UK and University of East Anglia, UK.
3) ***Fr2TSedCATE*** constructed from xxx treated sediment (TS; 30%) and surface horizon agricultural soil (SHS; 70%) (Figure 1.3); this soil recipe was created by LOMC, Le Havre University, France and CATE, France.

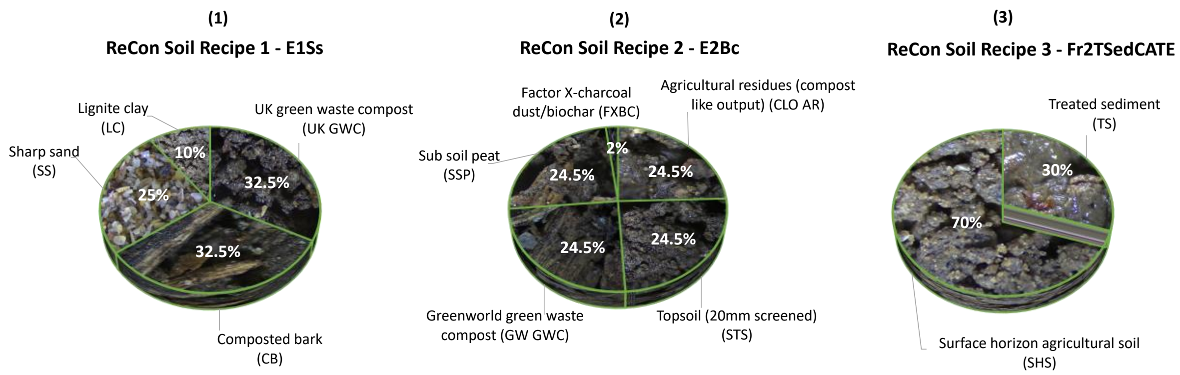

Figure 1. ReCon Soil constructed soils and their component materials. 1) ReCon Soil recipe 1 – E1Ss; 2) ReCon Soil recipe 2 – E2Bc; 3) ReCon Soil recipe 3 – Fr2SedCATE.

It is noted that the proportions stated above are percentage <u>by volume and include a nominal moisture content</u>. More information of the component materials is available in '***FACTSHEET – Carbon Profiling of ReCon Soil Component Materials***' (available in the ReCon Soil project toolkit archive).

Benchmarking Soils

Six natural soils (benchmarking soils) were collected at a depth of 0-10 cm from 6 locations in the France Chanel (Manche) England Programme area. The sampling locations are provided below (Figure 2). These natural soils were assessed for their key properties (Appendix A) and their carbon storage potential and used to benchmark the carbon storage potential of constructed soils.

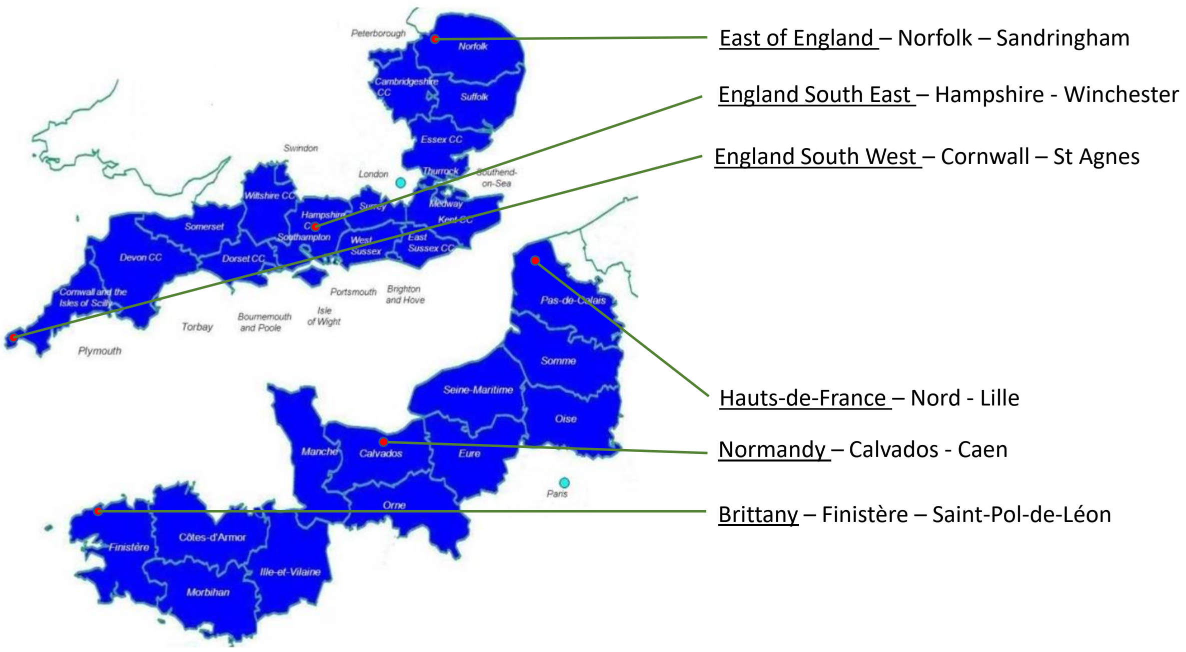

Figure 2. Benchmarking natural soil sampling locations/carbon modelling locations.

Methods

Moisture content (N = 3) was determined by drying soil samples in the oven at 80°C for 2 days.

To determine the other properties of the constructed soils and natural soils, all soil samples (N=3) were air dried, milled and then stored at 4 ˚C prior to assessment.

Soil bulk density was determined by cylinder methods (Hattey & Patton, 2019), soil samples (N = 5) were placed in a cylinder (100 ml) at gradually increased volumes (20 to 100 ml), then the soils were compacted, and weighted and volume recorded. All five pairs of mass and volume values were plotted as a scatter plot, with mass plotted on the y-axis and volume plotted on the x-axis. A "best-fit line" was then generated, and the gradient was determined as soil bulk density defined under a consolidated situation.

Soil texture (N = 3) was determined by 2-hour hydrometer methods (Gee & Bauder, 1986).

Organic matter (OM) was measured by loss on ignition (ISO, 1995). Samples (N = 3) were dried for 2 days (80 ˚C) and then combusted for 24 hours (450 ˚C).

Total carbon (**C**), nitrogen (N) and hydrogen (H) were determined using a flash combustion method (ISO, 1995) in a CHN analyser (CE440 Elemental Analyzer with an ECD detector, Exeter Analytical, Inc.).

Soil carbon stability profiles were measured using a Simultaneous DSC/TGA (Discovery SDT 650, TA Instruments). By calculating the mass losses across different temperature ranges, the fractions of relatively unstable OM, relatively stable OM and inorganic matter were ascribed. More details of this approach are available in '***FACTSHEET – Carbon Profiling of ReCon Soil Component Materials***' (available in the ReCon Soil project toolkit archive). This approach was used to profile carbon in the constructed soils and natural soils.

The data above (N = 3) was then used to populate a soil carbon fate model (K. Coleman & D. S. Jenkinson, 2014), the carbon model was modified and propagated using the soil carbon stability profiles (Mao et al., 2022). It was assumed that:

i. the constructed soils were deployed at the locations stated above (Figure 2), at a depth of 10 cm.
ii. there were no carbon inputs from other sources.
iii. the land was covered by vegetation every month of the year.

The input parameters used to inform the model are summarised in Appendix A. The model ascribed the estimates of remaining carbon stocks present in soil at 5 (short-term), 20 (medium-term) and 50 (long-term) years.

Results - Soil carbon profiles

Constructed soil E2Bc was observed to have the highest OC content (133 kg t^{-1}), relatively unstable OC (81 kg t^{-1}) and relatively stable OC (52 kg t^{-1}), while constructed soil Fr2SedCATE was observed to have the lowest OC content (26 kg t^{-1}), relatively unstable OC (17 kg t^{-1}) and relatively stable OC (9 kg t^{-1}) (Figure 3).

In general, natural soils were observed to have much less OC (11 to 68 kg t^{-1}), relatively unstable OC (5 to 31 kg t^{-1}) and relatively stable OC (4 to 51 kg t^{-1}) than the constructed soils (Figure 4). But in one case, natural soil ENSB had higher OC than constructed soil Fr2SedCATE (Figure 3.3 & 4.2).

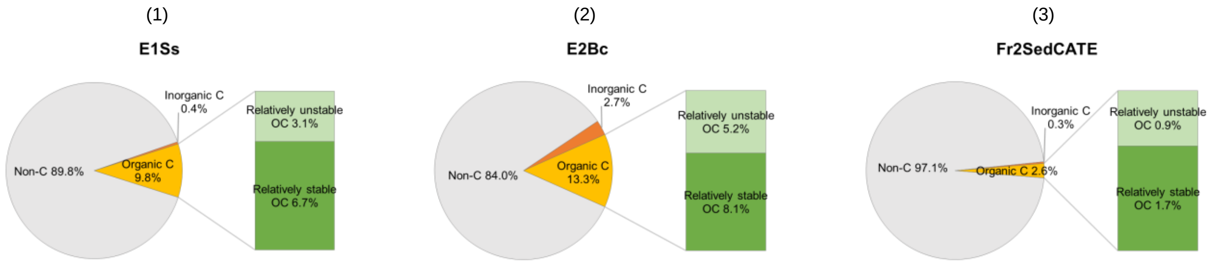

Figure 3. Component fractions of three ReCon Soil soil recipes - E1Ss (1); E2Bc (2); and Fr2SedCATE (3): non-carbon (*grey pie slice*), organic carbon (*yellow pie slice*), inorganic carbon (*orange pie slice*); relatively unstable organic carbon (*light green bar*), and relatively stable organic carbon (*dark green bar*).

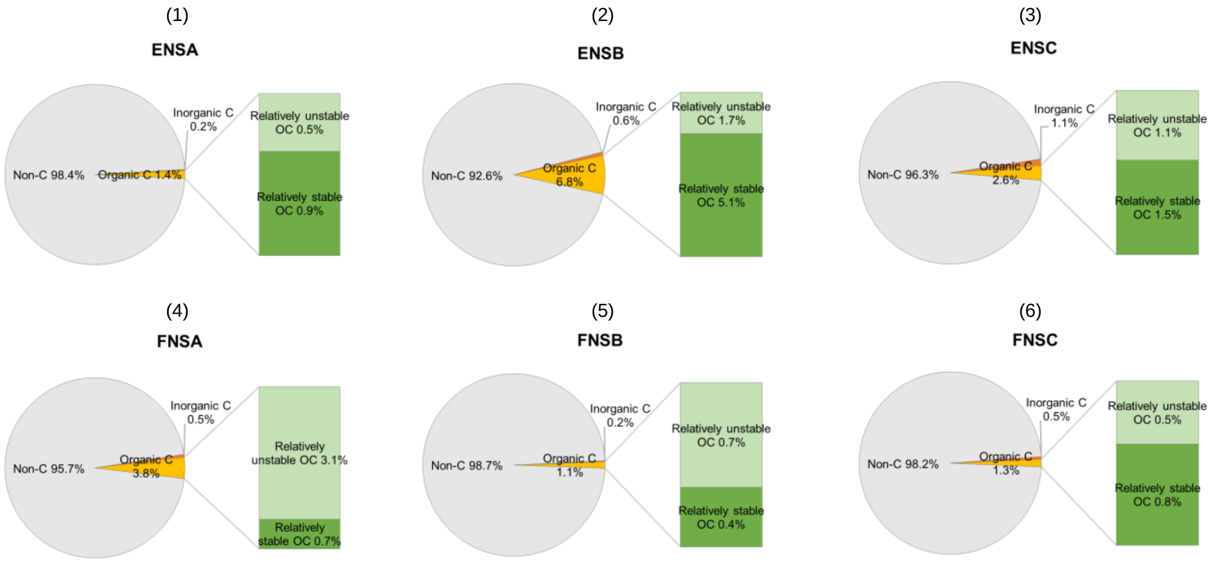

Figure 4. Component fractions of 6 natural soils – (1) England natural soil A (ENSA); (2) England natural soil B (ENSB); (3) England natural soil C (ENSC); (4) France natural soil A (FNSA); (5) France natural soil B (FNSB); (6) France natural soil C (FNSC): non-carbon (*grey pie slice*), organic carbon (*yellow pie slice*), inorganic carbon (*orange pie slice*); relatively unstable organic carbon (*light green bar*), and relatively stable organic carbon (*dark green bar*).

Results - Soil carbon modelling

The data generated from the carbon profiles and other input parameters (Appendix A) were used to model the fate of the carbon stocks in the constructed soils and natural soils. The model was used to simulate the turnover of organic carbon (OC) in assessed soils after 5, 20 and 50 years; thereby providing a prognosis of carbon storage potential of the constructed soils, benchmarking against the natural soils.

It was assumed that constructed soils were applied to land as topsoil (10 cm) at the 6 modelling locations. The carbon storage potential of the three constructed soils were benchmarked against the native natural soil at each modelling location.

E1Ss was ascribed a total OC stocks of 82.3 t ha^{-1}, with 32% being relatively unstable and 68% being relatively stable; E1Bc was ascribed a total OC stocks of 86.5 t ha^{-1}, with 39% being relatively unstable and 61% being relatively stable; and Fr2TSedCATE was ascribed a total OC stocks of 43.6 t ha^{-1}, with 33% being relatively unstable and 67% being relatively stable (Appendix A).

Modelling location 1 - Sandringham, Norfolk, UK

Assuming the three constructed soils (N = 3) were applied to modelling location1 - Sandringham, Norfolk, UK, the total OC stocks delivered by E1Ss, E1Bc and Fr2TSedCATE were predicted to be significantly ($P < 0.05$) higher (4.6-, 4.9- and 2.5-fold, respectively) than in the benchmarking natural soil ENSA (17.7 t ha^{-1}) (Appendix A).

After 5 years (short-term), 17.5, 17.9 and 9.8 t ha^{-1} of total OC stocks were predicted by the modelling to remain in E1Ss, E1Bc and Fr2TSedCATE (Figure 5). Total OC stocks in E1Ss, E1Bc and Fr2TSedCATE were predicted to be significantly ($P < 0.05$) higher (4.5-, 4.6- and 2.5-fold, respectively) than in natural soil ENSA (3.9 t ha^{-1}) (Figure 5).

After 20 years (medium-term), 5.6, 6.3 and 3.5 t ha^{-1} of total OC stocks were predicted by the modelling to remain in E1Ss, E1Bc and Fr2TSedCATE (Figure 5). Total OC stocks in E1Ss, E1Bc and Fr2TSedCATE were predicted to be significantly ($P < 0.05$) higher (4.0-, 4.5- and 2.5-fold, respectively) than in natural soil ENSA (1.4 t ha^{-1}) (Figure 5).

After 50 years (long-term), 3.3, 3.8 and 2.1 t ha^{-1} of total OC stocks were predicted by the modelling to remain in E1Ss, E1Bc and Fr2TSedCATE (Figure 5). Total OC stocks in E1Ss, E1Bc and Fr2TSedCATE were predicted to be significantly ($P < 0.05$) higher (4.1-, 4.8- and 2.6-fold, respectively) than in natural soil ENSA (0.8 t ha^{-1}) (Figure 5).

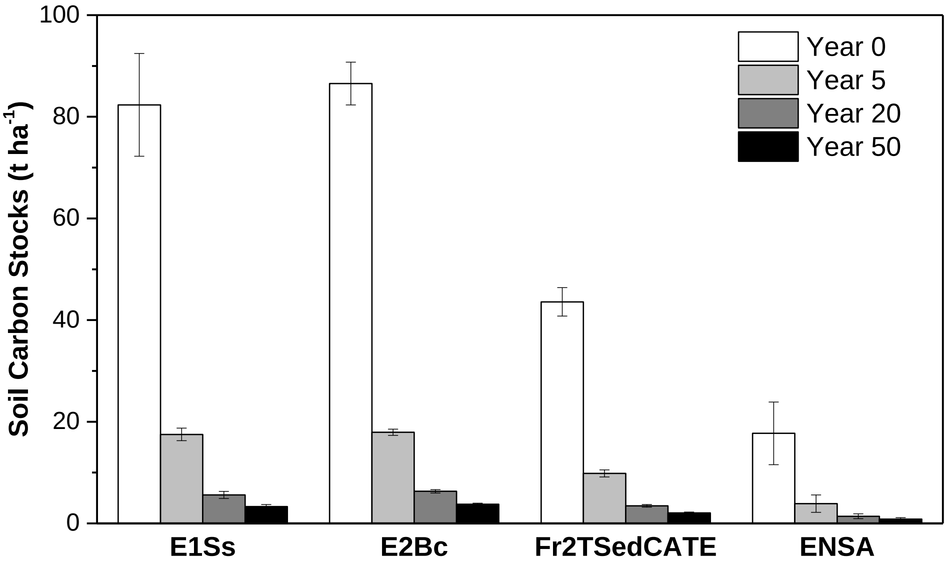

Figure 5. Variations in total C stocks (t C ha^{-1}) at the time of deployment, after 5, 20 and 50 years in ReCon Soil constructed soils - E1Ss; E2Bc; and Fr2SedCATE and benchmarking natural soil ENSA, at modelling location Sandringham, Norfolk, UK.

Modelling location 2 – Winchester, Hampshire, UK

Assuming the three constructed soils were applied to modelling location 2 - Winchester, Hampshire, UK, the total OC stocks delivered by E1Ss and E1Bc were predicted to be higher (1.2- and 1.3-fold, respectively) than in the benchmarking natural soil ENSB (66.4 t ha^{-1}), but only E1Bc was observed to be significantly ($P < 0.05$) higher (Appendix A). While Fr2TSedCATE was predicted to delivers significantly ($P < 0.05$) less OC than the benchmarking natural soil ENSB.

After 5 years (short-term), 16.8, 17.0 and 9.3 t ha^{-1} of total OC stocks were predicted by the modelling to remain in E1Ss, E1Bc and Fr2TSedCATE (Figure 6). Total OC stocks in benchmarking natural soil ENSB was predicted to be 16.0 t ha^{-1} (Figure 6).

After 20 years (medium-term), 5.5, 6.2 and 3.4 t ha^{-1} of total OC stocks were predicted by the modelling to remain in E1Ss, E1Bc and Fr2TSedCATE (Figure 6). Total OC stocks in benchmarking natural soil ENSB was predicted to be 5.8 t ha^{-1} (Figure 6).

After 50 years (long-term), 3.2, 3.6 and 2.0 t ha^{-1} of total OC stocks were predicted by the modelling to remain in E1Ss, E1Bc and Fr2TSedCATE (Figure 6). Total OC stocks in benchmarking natural soil ENSB was predicted to be 3.4 t ha^{-1} (Figure 6).

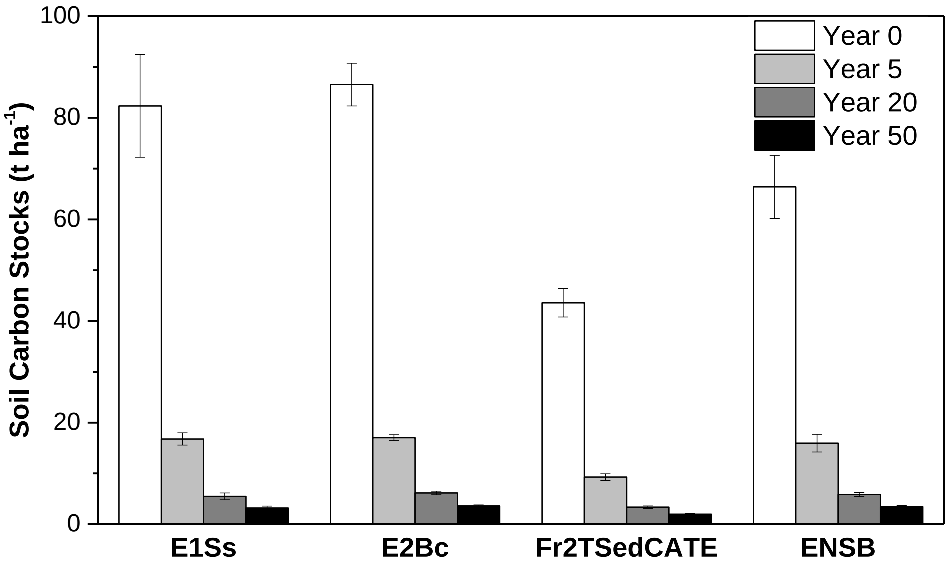

Figure 6. Variations in total C stocks (t C ha^{-1}) at the time of deployment, after 5, 20 and 50 years in ReCon Soil constructed soils - E1Ss; E2Bc; and Fr2SedCATE and benchmarking natural soil ENSB, at modelling location Winchester, Hampshire, UK.

Modelling location 3 – St Agnes, Cornwall, UK

Assuming the three constructed soils were applied to Modelling location 3 – St Agnes, Cornwall, UK, the total OC stocks delivered by E1Ss, E1Bc and Fr2TSedCATE were predicted to be significantly ($P < 0.05$) higher (3.6-, 3.8- and 1.9-fold, respectively) than in the benchmarking natural soil ENSC (22.8 t ha^{-1}) (Appendix A).

After 5 years (short-term), 15.7, 16.0 and 8.7 t ha^{-1} of total OC stocks were predicted by the modelling to remain in E1Ss, E1Bc and Fr2TSedCATE (Figure 7). Total OC stocks in E1Ss, E1Bc and Fr2TSedCATE were predicted to be significantly ($P < 0.05$) higher (3.4-, 3.5- and 1.9-fold, respectively) than in natural soil ENSC (4.6 t ha^{-1}) (Figure 7).

After 20 years (medium-term), 5.3, 6.0 and 3.3 t ha^{-1} of total OC stocks were predicted by the modelling to remain in E1Ss, E1Bc and Fr2TSedCATE (Figure 7). Total OC stocks in E1Ss, E1Bc and Fr2TSedCATE were predicted to be significantly ($P < 0.05$) higher (2.7-, 3.0- and 1.7-fold, respectively) than in natural soil ENSC (2.0 t ha^{-1}) (Figure 7).

After 50 years (long-term), 3.0, 3.4 and 1.9 t ha^{-1} of total OC stocks were predicted by the modelling to remain in E1Ss, E1Bc and Fr2TSedCATE (Figure 7). Total OC stocks in E1Ss, E1Bc and Fr2TSedCATE were predicted to be significantly ($P < 0.05$) higher (2.7-, 3.1- and 1.7-fold, respectively) than in natural soil ENSC (1.1 t ha^{-1}) (Figure 7).

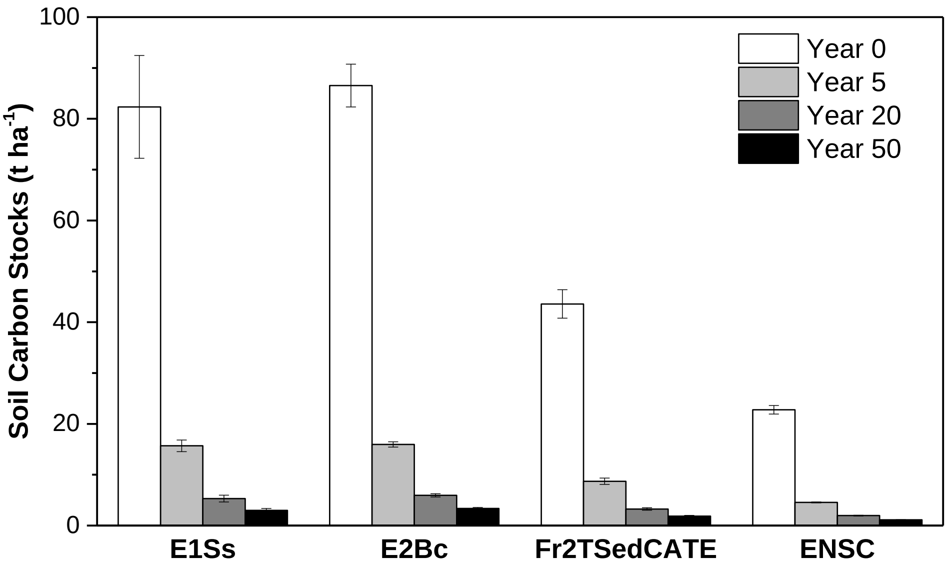

Figure 7. Variations in total C stocks (t C ha^{-1}) at the time of deployment, after 5, 20 and 50 years in ReCon Soil constructed soils - E1Ss; E2Bc; and Fr2SedCATE and benchmarking natural soil ENSC, at modelling location St Agnes, Cornwall, UK.

Modelling location 4 – Lille, Nord, France

Assuming the three constructed soils were applied to Modelling location 4 – Lille, Nord, France, the total OC stocks delivered by E1Ss, E1Bc and Fr2TSedCATE were predicted to be significantly ($P < 0.05$) higher (2.9-, 3.1- and 1.6-fold, respectively) than in the benchmarking natural soil ENSC (28.1 t ha^{-1}) (Appendix A).

After 5 years (short-term), 16.8, 17.0 and 9.3 t ha^{-1} of total OC stocks were predicted by the modelling to remain in E1Ss, E1Bc and Fr2TSedCATE (Figure 8). Total OC stocks in E1Ss, E1Bc and Fr2TSedCATE were predicted to be significantly ($P < 0.05$) higher (4.7-, 4.7- and 2.6-fold, respectively) than in natural soil ENSC (3.6 t ha^{-1}) (Figure 8).

After 20 years (medium-term), 5.5, 6.2 and 3.4 t ha^{-1} of total OC stocks were predicted by the modelling to remain in E1Ss, E1Bc and Fr2TSedCATE (Figure 8). Total OC stocks in E1Ss, E1Bc and Fr2TSedCATE were predicted to be significantly ($P < 0.05$) higher (2.8-, 3.1- and 1.7-fold, respectively) than in natural soil ENSC (2.0 t ha^{-1}) (Figure 8).

After 50 years (long-term), 3.2, 3.6 and 2.0 t ha^{-1} of total OC stocks were predicted by the modelling to remain in E1Ss, E1Bc and Fr2TSedCATE (Figure 8). Total OC stocks in E1Ss, E1Bc and Fr2TSedCATE were predicted to be significantly ($P < 0.05$) higher (2.7-, 3.0- and 1.7-fold, respectively) than in natural soil ENSC (1.2 t ha^{-1}) (Figure 8).

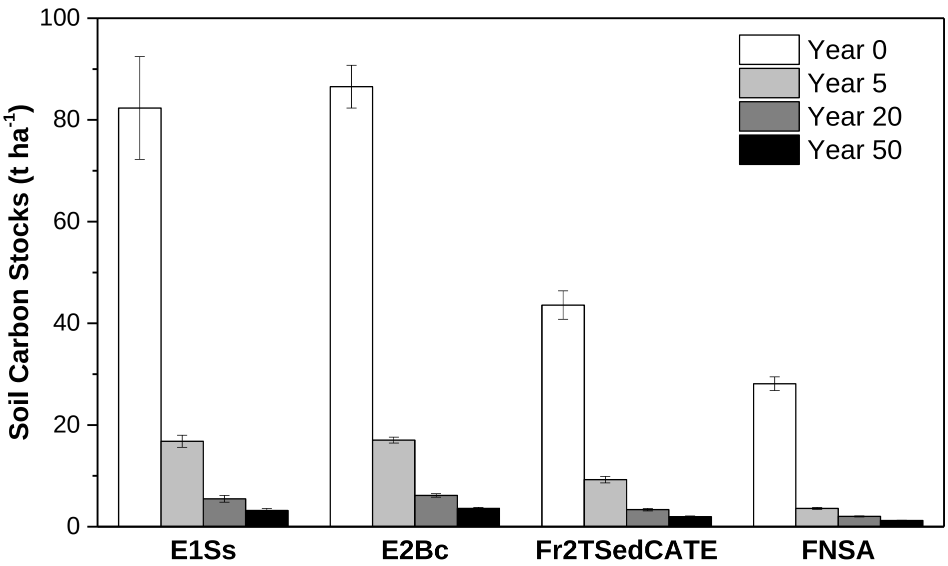

Figure 8. Variations in total C stocks (t C ha^{-1}) at the time of deployment, after 5, 20 and 50 years in ReCon Soil constructed soils - E1Ss; E2Bc; and Fr2SedCATE and benchmarking natural soil FNSA, at modelling location Lille, Nord, France.

Modelling location 5 – Caen, Calvados, France

Assuming the three constructed soil were applied to Modelling location 5 – Caen, Calvados, France, the total OC stocks delivered by E1Ss, E1Bc and Fr2TSedCATE were predicted to be significantly ($P < 0.05$) higher (7.7-, 8.1- and 4.1-fold, respectively) than in the benchmarking natural soil FNSB (10.7 t ha^{-1}) (Appendix A).

After 5 years (short-term), 15.6, 16.1 and 8.8 t ha^{-1} of total OC stocks were predicted by the modelling to remain in E1Ss, E1Bc and Fr2TSedCATE (Figure 9). Total OC stocks in E1Ss, E1Bc and Fr2TSedCATE were predicted to be significantly ($P < 0.05$) higher (8.7-, 8.9- and 4.9-fold, respectively) than in natural soil FNSB (1.8 t ha^{-1}) (Figure 9).

After 20 years (medium-term), 5.3, 6.0 and 3.3 t ha^{-1} of total OC stocks were predicted by the modelling to remain in E1Ss, E1Bc and Fr2TSedCATE (Figure 9). Total OC stocks in E1Ss, E1Bc and Fr2TSedCATE were predicted to be significantly ($P < 0.05$) higher (5.9-, 6.7- and 3.7-fold, respectively) than in natural soil FNSB (0.9 t ha^{-1}) (Figure 9).

After 50 years (long-term), 3.0, 3.4 and 1.9 t ha^{-1} of total OC stocks were predicted by the modelling to remain in E1Ss, E1Bc and Fr2TSedCATE (Figure 9). Total OC stocks in E1Ss, E1Bc and Fr2TSedCATE were predicted to be significantly ($P < 0.05$) higher (6.0-, 6.8- and 3.8-fold, respectively) than in natural soil ENSC (0.5 t ha^{-1}) (Figure 9).

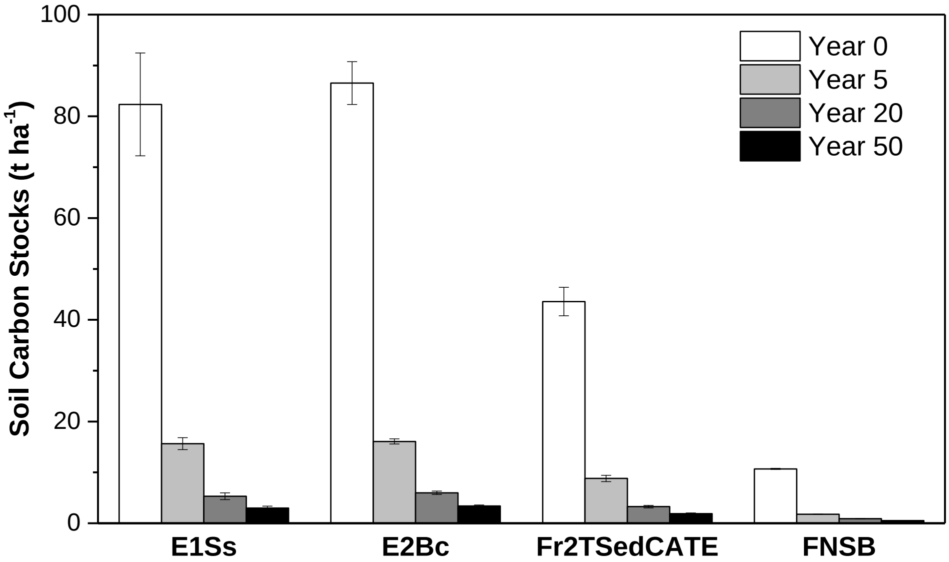

Figure 9. Variations in total C stocks (t C ha^{-1}) at the time of deployment, after 5, 20 and 50 years in ReCon Soil constructed soils - E1Ss; E2Bc; and Fr2SedCATE and benchmarking natural soil FNSA, at modelling location Caen, Calvados, France.

Modelling location 6 – Saint-Pol-de-Léon, Brittany, France

Assuming the three constructed soils were applied to Modelling location 6 – Saint-Pol-de-Léon, Brittany, France, the total OC stocks delivered by E1Ss, E1Bc and Fr2TSedCATE were predicted to be significantly ($P < 0.05$) higher (5.3-, 5.6- and 2.8-fold, respectively) than in the benchmarking natural soil FNSC (15.4 t ha^{-1}) (Appendix A).

After 5 years (short-term), 14.2, 14.6 and 8.0 t ha^{-1} of total OC stocks were predicted by the modelling to remain in E1Ss, E1Bc and Fr2TSedCATE (Figure 10). Total OC stocks in E1Ss, E1Bc and Fr2TSedCATE were predicted to be significantly ($P < 0.05$) higher (5.3-, 5.4- and 3.0-fold, respectively) than in natural soil FNSC (2.7 t ha^{-1}) (Figure 10). Most relatively unstable OC

After 20 years (medium-term), 5.1, 5.7 and 3.1 t ha^{-1} of total OC stocks were predicted by the modelling to remain in E1Ss, E1Bc and Fr2TSedCATE (Figure 10). Total OC stocks in E1Ss, E1Bc and Fr2TSedCATE were predicted to be significantly ($P < 0.05$) higher (4.6-, 5.2- and 2.8-fold, respectively) than in natural soil FNSC (1.1 t ha^{-1}) (Figure 10).

After 50 years (long-term), 2.7, 3.1 and 1.7 t ha^{-1} of total OC stocks were predicted by the modelling to remain in E1Ss, E1Bc and Fr2TSedCATE (Figure 10). Total OC stocks in E1Ss, E1Bc and Fr2TSedCATE were predicted to be significantly ($P < 0.05$) higher (4.5-, 5.2- and 2.8-fold, respectively) than in natural soil FNSC (0.6 t ha^{-1}) (Figure 10).

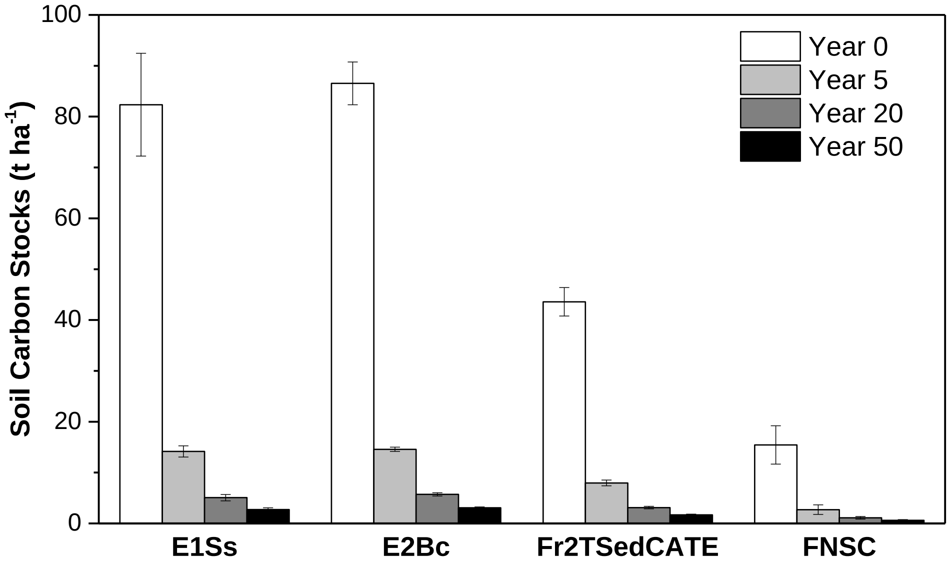

Figure 10. Variations in total C stocks (t C ha^{-1}) at the time of deployment, after 5, 20 and 50 years in ReCon Soil constructed soils - E1Ss; E2Bc; and Fr2SedCATE and benchmarking natural soil FNSC, at modelling location Saint-Pol-de-Léon, Brittany, France.

Carbon storage potential of constructed soils

Organic carbon entrained within a constructed soil has the potential to contribute in two ways. Firstly, it has the potential to nourish the soil and facilitate proliferation of the soil ecosystem. The base of the soil ecosystem is OC, this is consumed by many microorganisms (bacteria/fungi) and these in turn support the next trophic level. Soil devoid of OC has limited potential to support soil biology. Secondly, OC can persist for a long period of time. Thus, offering opportunity for long-term carbon storage.

The carbon storage potential of constructed soils would vary depending on the carbon profiles of the soil, the location where it is applied to, and the climate conditions the soil is exposed to. Six locations were modelled, in general, constructed soils decomposed the fastest at modelling location 6 - Saint-Pol-de-Léon, Brittany, France and the slowest at the modelling location 1 - Sandringham, Norfolk, UK.

At all six modelling locations, E2Bc had the largest carbon storage potential and could delivery 3.1 to 3.8 t ha^{-1} long-term carbon stocks (remains in soil after 50 years). E1Ss had the second largest carbon storage potential and could delivery 2.7 to 3.3 t ha^{-1} long-term carbon stocks (remains in soil after 50 years). Fr2TSedCATE had the lowest carbon storage potential and could deliver 1.7 to 2.1 t ha^{-1} long-term carbon stocks (remains in soil after 50 years). Only one natural soil ENSB had relatively high carbon storage potential and 3.4 t ha^{-1} of OC was predicted to remain in soil after 50 years. The other benchmarking natural soils had considerable low carbon storage potential and 0.5 to 1.2 t ha^{-1} of OC was predicted to remain in soil after 50 years.

It follows that the long-term carbon storage potential of the constructed soils (E1Ss, E2Bc and Fr2TSedCATE), and thus their potential carbon off-set potential, is considerable, and could afford enhanced carbon storage benefits beyond the native benchmarking soils.

References

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Appendix A:

Soil carbon modelling input parameters

Soil data	
Modelling location	See Figure 2
Soil clay content (%)	
Soil sample depth (cm)	10 cm
Soil C input	See the table below
Land management data	
C input	No additional carbon input
Soil cover	Soil is covered with vegetated every month
Weather data	
Monthly air temperature (˚C)	Obtained for each modelling location (1991 – 2021) from Climate-Data.org. (Climate-Data.org., 2023)
Monthly rainfall (mm)*	Obtained for each modelling location (1991 – 2021) from Climate-Data.org. (Climate-Data.org., 2023)
Monthly open pan evaporation (mm)**	Monthly potential evapotranspiration (PET) was obtained from the Müller's collection (Müller, 2012) for the most similar site to the modelling location. PET values were converted to open-pan evaporation by dividing by 0.75 (K. Coleman & D. Jenkinson, 2014).

Key properties and initial soil carbon input of ReCon Soil soils and natural soils (*dry matter basis unless otherwise stated*)

N=5 for soil density testing and N=3 for all other measurements.

Soil	**Soil density** g cm^{-3}	**OMa** %	**TCb** %	**TNc** %	**THd** %	**C:N ratioe**	**OC input at depth of 10 cm** t ha^{-1}
E1Ss	0.84	15.4 ± 8.0	11.1 ± 2.0	0.3 ± 0.05	0.8 ± 0.3	34:1	82.3 ± 10.1
E2Bc	0.65	21.6 ± 2.7	16.1 ± 0.9	1.0 ± 0.1	1.5 ± 0.2	16:1	86.5 ± 4.2
Fr2TSedCATE	1.66	3.1 ± 0.1	3.0 ± 0.2	5.8 ± 0.6	0.3 ± 0.02	1:1	43.6 ± 2.8
ENSA	1.21	3.2 ± 0.2	1.6 ± 0.5	0.1 ± 0.05	0.2 ± 0.02	12:1	12.7 ± 6.2
ENSB	0.97	9.8 ± 0.4	7.5 ± 0.7	0.5 ± 0.05	0.9 ± 0.1	15:1	66.4 ± 6.2
ENSC	0.89	7.8 ± 0.8	3.6 ± 0.2	0.4 ± 0.1	0.9 ± 0.02	9:1	22.8 ± 0.9

[a]OM: organic matter.
[b]TC: total carbon.
[c]TN: total nitrogen.
[d]TH: total hydrogen
[e]C:N ration: carbon:nitrogen ratio.