ReCon Soil - Reconstructed Soils from Waste

FACTSHEET

– Carbon Profiling of ReCon Soil Component Materials

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Overview

This factsheet accounts the carbon stability profiles of two reference materials (cellulose and lignin) and 31 candidate component materials with potential to be used to construct soils. The data herein underpins the ReCon Soil decision support tool for carbon reckoning in soils created from the blending of component materials in user specified proportions (CarbonReConer© *Soil Recipe Design Tool*).

Methods

All samples (N=3) were air dried, milled and then stored at 4 ˚C prior to assessment.

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.).

Thermogravimetry (TGA) and **differential scanning calorimetry (DSC)** were performed simultaneously using a Simultaneous DSC/TGA (Discovery SDT 650, TA Instruments). TGA is a quantitative technique which measures the mass change of a substance as it is heated, while DSC measures the heat-flow. TGA and DSC were used to profile carbon in the candidate materials. Cellulose and Lignin were used as reference materials.

Candidate materials

As highlighted in Table 1, numerous and varied "waste" materials hold potential to be used as components of a constructed soil. These materials have a wide range of properties that could deliver desirable traits to constructed soils. For example, some materials (e.g. sand) might promote free drainage in a constructed soil, while others (e.g. compost) might impart high organic matter contents to a constructed soil. *It is emphasised that where any material is to be used as a component in a constructed soil it must comply with standards/regulations regarding its safety.*

Table 1. Candidate materials considered under the ReCon Soil project

Component type	Material type	Material	Supplier
Organic materials	Compost*	UK green waste compost (UK GWC)	Eden Project, UK
		CATE compost (FR GWC)	CATE, France
		Seed sowing compost (SSC)	Westland Horticulture Ltd, UK
		Mature plant compost (MAPC)	Westland Horticulture Ltd, UK
		Multi-purpose compost (MUPC)	Levington compost, Nottcuts, UK
		Greenworld green waste compost (GW GWC)	Greenworld Sales Ltd, UK
	Composted bark*	Composted bark (CB)	Eden Project, UK
	Anaerobic digestate#	Maurice Mason anaerobic digestate (MM AD)	Maurice Mason Ltd, UK
	Paper recycling co-product#	Paper crumble (PC)	Palm Paper Ltd, UK
	Biochar#	Hardwood oak biochar (HW BC)	University of East Anglia, UK
		Softwood BD (Cuø) biochar (SW BC)	University of East Anglia, UK
		Carbon Gold biochar (CG BD)	Carbon Gold Ltd, UK
		UK biochar (UK BC)	Carbon Gold Ltd, UK
		Factor X-charcoal dust/biochar (FXBC)	Greenworld Sales Ltd, UK
Mineral materials	Sand#	Sharp sand (SS)	Eden Project, UK
	Clay#	Lignite clay (LC)	Imerys (Newton Abbot), UK
Potential waste materials	Sludge#	Quarry mineral sludge (QMS)	HAROPA PORT, France
	Excavated soil#	Excavated clay soil (ExS)	BRGM, France
	Sediment#	Treated sediment (TS)	LOMC, Le Havre University, France
		Non-treated sediment (NTS)	Tancarville, France
	Sawdust#	Mixed hardwood sawdust (MHS)	University of East Anglia, UK
	Agricultural waste#	Agricultural residues (compost like output) (CLO AR)	Greenworld Sales Ltd, UK
	Brash chippings#	Brash chippings (BRC)	Greenworld Sales Ltd, UK
	Brewery waste#	Spent brewery grain (SBG)	University of East Anglia, UK
	Coffee waste#	Coffee grounds (CG)	University of East Anglia, UK
	Tea waste#	Used tea and tea bags (T&TB)	University of East Anglia, UK
	Construction soil waste#	Sub soil peat (SSP)	Greenworld Sales Ltd, UK
Soils	Topsoil	Topsoil (20mm screened) (STS)	Greenworld Sales Ltd, UK
		Topsoil (WH TS)	Westland Horticulture Ltd, UK
	Agricultural soil	Surface horizon agricultural soil (SHS)	CATE, France
		Deep horizon agricultural soil (DHS)	CATE, France

*These composted materials must comply with 'PAS 100, Publicly Available Specification for Composted Materials' criteria.

#These materials must be assessed and deemed to be uncontaminated and safe to use.

Results

References materials cellulose and lignin were used to benchmark the TGA/DSC profiles. Their TGA/DSC profiles are presented below (Figure 1).

Attrition of cellulose occurred between 130 – 400˚C (Figure 1). When the temperature was higher than 400 ˚C but less than 600˚C, a small amount of cellulose residue (~13%) was decomposed. Complete attrition of cellulose was realised by a temperature of 600 ˚C. Attrition of lignin occurred over a wider temperature range, with two phases being observed: phase 1 (120 - 450˚C) and phase 2 (450 - 750 ˚C) with slower mass loss rates (Figure 1). Complete attrition of lignin was realised by a temperature of 750˚C. These results confirm greater stability for lignin over cellulose, and are in agreement with previous studies (Rao & Sharma, 1998; Yang et al., 2007). DSC traces showed positive inflections where mass loss was accompanied by organic matter (exothermic) loss. Together the derivative thermogravimetric (DTG) mass loss profile and the DSC heat-flow provide the insights to define the temperature ranges stated above. These ranges were used as a benchmark to consider proportions of relatively unstable and relatively stable carbon in the candidate materials.

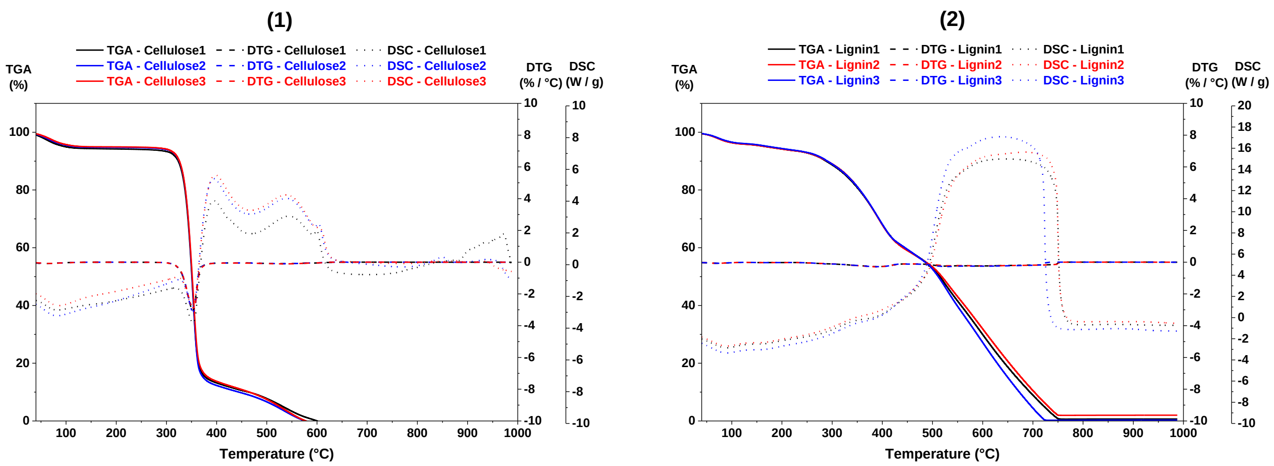

Figure 1. Thermogravimetric analysis (TGA) curves (*solid line*), derivative thermogravimetric (DTG) curves (*dashed line*) and differential scanning calorimetry (DSC) curves (*dotted line*) of **cellulose** (1) and **lignin** (2) (N=3).

Thereafter, TGA and DSC were used to profile the carbon stability for each candidate material. TGA/DSC profiling of all component materials revealed at least three phases.

Phase 1: moisture evaporation
Phase 2: attrition of organic matter
Phase 3: attrition of inorganic matter.

In some materials two obvious *sub-phases* were observed in organic matter attrition (Phase 2) and they were assigned to relatively stable organic matter (observed at a higher temperature range) and relatively unstable organic matter (observed at a lower temperature range). Where no obvious *sub-phases* were observed in Phase 2, 400 ˚C (commensurate with the end of cellulose attrition) was used as the separation point for the relatively unstable/stable fractions of OM.

The proportions of relatively unstable and relatively stable organic matter were then reconciled with the elemental carbon content of the candidate materials to ascribe mass of carbon in each stability fraction (per unit mass of candidate material, on a dry mass basis).

Exemplar 1 – Organic materials

Green waste compost (UK GWC) was selected to exemplify the carbon profiling of organic materials. Compost is known to be organic matter rich and has been used as a soil amendment to improve plant growth.

TGA/DSC profiling of UK GWC revealed four phases in the attrition process. These were assigned to: moisture evaporation, combustion of relatively unstable components (e.g. cellulose like), combustion of relatively stable components (e.g. lignin like) and attrition of inorganic carbonates (Figure 2.1). Using the mass loss fractions calculated from the profiling and the elemental carbon content of UK GWC (20.3%$_{\text{dry mass}}$), the dry mass of UK GWC was ascribed to non-carbon (79.7%), organic carbon (OC; 19.3%) and inorganic carbon (1.0%) (Figure 2.2). Within the OC fraction, 48% was defined as relatively unstable and 52% was defined as relatively stable (Figure 2.2). On a dry mass base, UK GWC contained 92 kg t^{-1} relatively unstable OC and 101 kg t^{-1} relatively stable OC.

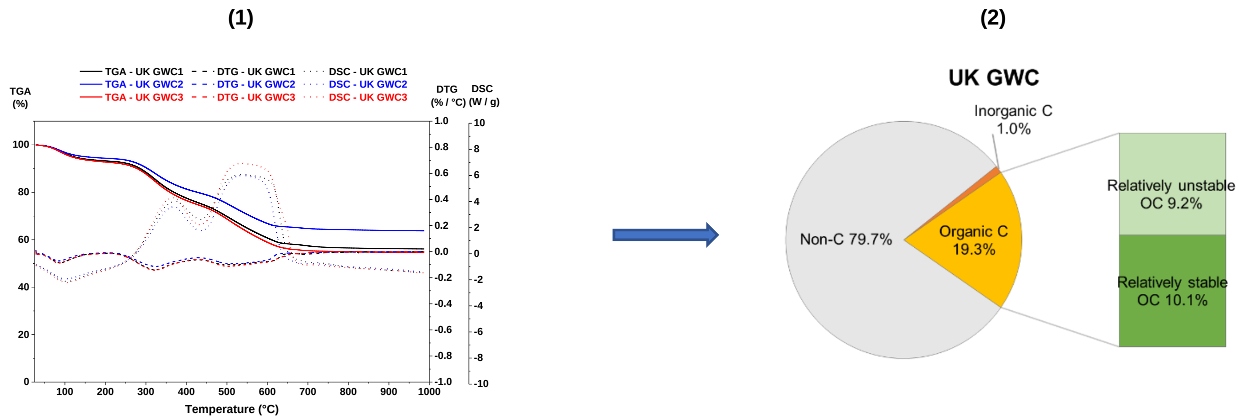

Figure 2. (1): Thermogravimetric analysis (TGA) curves (*solid line*), derivative thermogravimetric (DTG) curves (*dashed line*) and differential scanning calorimetry (DSC) curves (*dotted line*) of **UK green waste compost (UK GWC)** (N=3); and (2) component fractions of UK GWC: non-carbon (*grey pie 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*).

Exemplar 2 – Mineral materials

Mineral materials are an important part of soil composition. They can impart strength, and as linked to their particle size, influence hydrology of a soil. Sharp sand (SS) was selected to exemplify the carbon profiling of mineral materials. SS contained only a very small amount of organic carbon (0.3%), most of the SS was comprised of non-carbon materials (99.6%) (Figure 3.2).

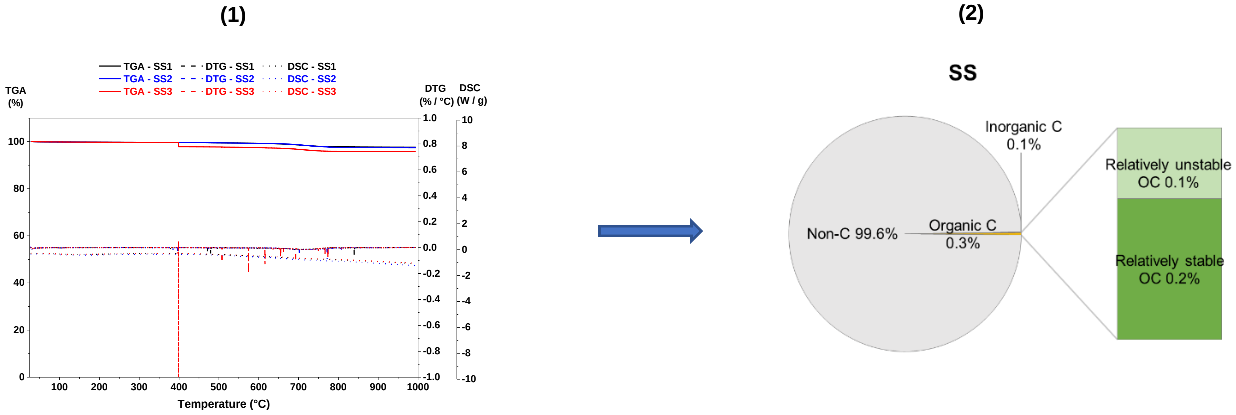

Figure 3. (1): Thermogravimetric analysis (TGA) curves (*solid line*), derivative thermogravimetric (DTG) curves (*dashed line*) and differential scanning calorimetry (DSC) curves (*dotted line*) of **sharp sand (SS)** (N=3); and (2) component fractions of SS: non-carbon (*grey pie slice*), organic carbon (*yellow pie slice*), inorganic carbon (*orange pie slice*); relatively unstable organic carbon (*light green bar*), and relatively stable organic carbon (*dark green bar*).

Exemplar 3 – Further potential materials

Numerous and varied “waste” materials hold potential to be used as components in a constructed soil (see Table 1). Treated sediment (TS) was selected to exemplify the carbon profiling of the potential materials category.

TGA/DSC profiling of TS revealed four phases in the attrition process. These were assigned to: moisture evaporation, combustion of relatively unstable components, combustion of relatively stable components and attrition of inorganic carbonates. Using the mass loss fractions calculated from the profiling and the elemental carbon content of TS (6.6%$_{\text{dry mass}}$), the dry mass of TS was ascribed to non-carbon (93.4%), organic carbon (5.9%) and inorganic carbon (0.7%) (Figure 4.2). Within the OC fraction, 25% was defined as relatively unstable and 75% was defined as relatively stable (Figure 4.2). On a dry mass base, TS contained 15 kg t^{-1} relatively unstable OC and 44 kg t^{-1} relatively stable OC.

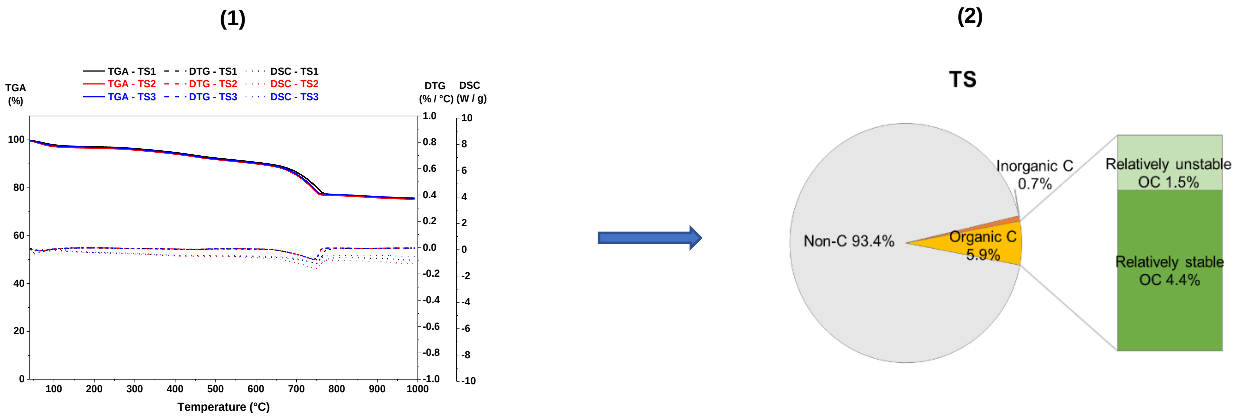

Figure 4. (1): Thermogravimetric analysis (TGA) curves (*solid line*), derivative thermogravimetric (DTG) curves (*dashed line*) and differential scanning calorimetry (DSC) curves (*dotted line*) of **treated sediment (TS)** (N=3); and (2) component fractions of TS: non-carbon (*grey pie slice*), organic carbon (*yellow pie slice*), inorganic carbon (*orange pie slice*); relatively unstable organic carbon (*light green bar*), and relatively stable organic carbon (*dark green bar*).

Exemplar 4 – Soils

Both commercial topsoil and agricultural soils have the potential to be used as components in constructed soils. Surface horizon agricultural soil (SHS) was selected to exemplify the carbon profiling for soils.

TGA/DSC profiling of SHS revealed four phases in the attrition process. These were assigned to: moisture evaporation, combustion of relatively unstable components, combustion of relatively stable components and attrition of inorganic carbonates. Using the mass loss fractions calculated from the profiling and the elemental carbon content of SHS (1.9%$_{\text{dry mass}}$), the dry mass of SHS was ascribed to non-carbon (98.2%), organic carbon (1.3%) and inorganic carbon (0.5%) (Figure 5.2). Within the OC fraction, 38% was defined as relatively unstable and 62% was defined as relatively stable (Figure 5.2). On a dry mass base, TS contained 5 kg t^{-1} relatively unstable OC and 8 kg t^{-1} relatively stable OC.

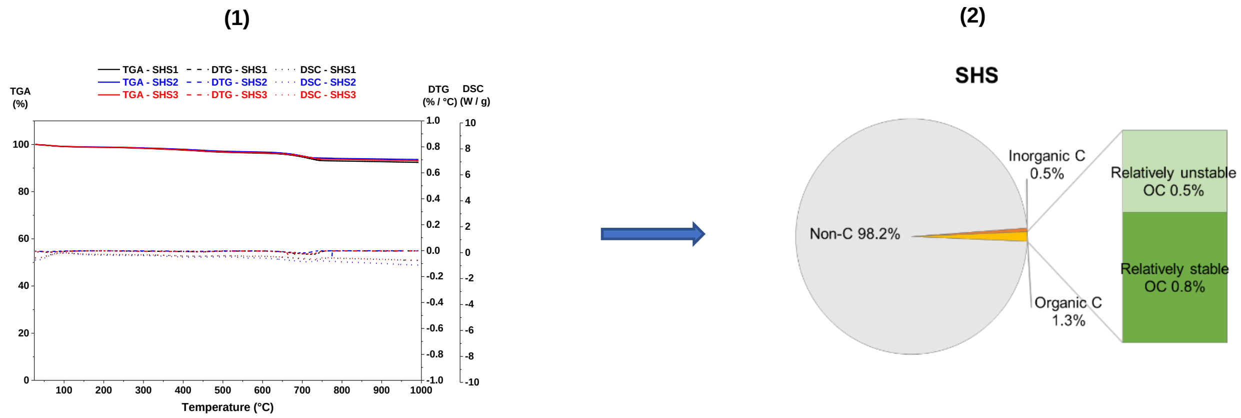

Figure 5. (1): Thermogravimetric analysis (TGA) curves (*solid line*), derivative thermogravimetric (DTG) curves (*dashed line*) and differential scanning calorimetry (DSC) curves (*dotted line*) of **surface horizon of agricultural soil (SHS)** (N=3); and (2) component fractions of SHS: non-carbon (*grey 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*).

Synopsis of candidate material

In total, 31 materials were screened (Table 1). These materials were categorised into 4 groups: i) Organic materials; ii) Mineral materials; iii) Potential waste materials, and; iv) Soils.

A variety of composts were screened. Greenworld Green Waste Compost (GW GWC) had the highest OC content (243 kg t^{-1}; with 58% relatively unstable OC and 42% relatively stable OC), mature plant compost (MAPC) had the lowest OC content (36 kg t^{-1}; with 92% relatively unstable OC and 18% relatively stable OC) (Appendix A).

Other organic materials screened included composted bark (CB), anaerobic digestate (MM AD), paper crumble (PC) and a variety of biochars. These materials have already been used as soil conditioners and have the potential to be used as component materials in constructed soils. Per ton of material (on a dry weight basis) CB had 211 kg of relatively unstable OC and 230 kg of relatively stable OC (Appendix A). While MM AD had 251 kg of relatively unstable OC and 99 kg of relatively stable OC (Appendix A). With notably lower amounts, PC had 39 kg of relatively unstable OC and 47 kg of relatively stable OC (Appendix A). All biochars contained a large amount of OC (387 to 788 t kg^{-1}), with a large proportion of relatively stable OC (55 to 96% of OC) (Appendix A).

The OC content of potential waste materials screened varied. Coffee grounds (CG) had the highest OC content (479 kg t^{-1}) while quarry mineral sludge (QMS) had the lowest OC content (1 kg t^{-1}) (Appendix A). Brash chippings (BRC) had the highest relatively stable OC content (115 kg t^{-1}), while quarry mineral sludge (QMS) had the lowest relatively stable OC content (1 kg t^{-1}) (Appendix A).

Two commercial topsoil and two agricultural soils were screened as potential candidate materials for developing constructed soils. Commercial topsoil had relatively high OC (35 to 51 kg t^{-1}), while agricultural soils had relatively low OC (6 to 14 kg t^{-1}).

The screening of the 31 materials makes clear that total carbon present across the materials varied and that proportions of relatively unstable and relatively stable OC also varied (Figure 6).

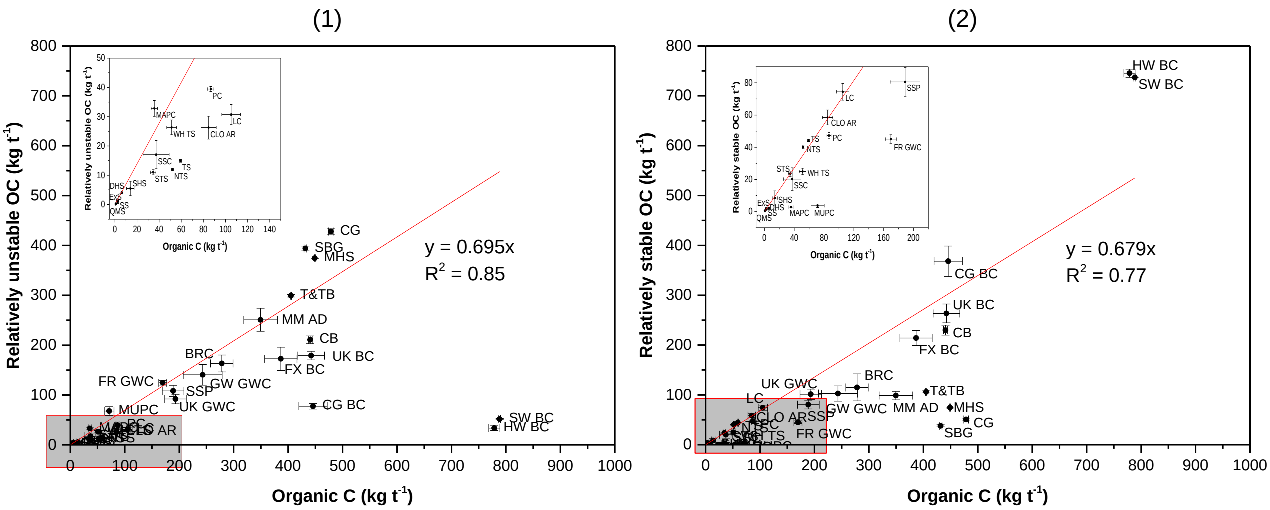

Figure 6. Correlation of organic carbon (kg t^{-1}) and relatively unstable organic carbon (kg t^{-1}) of candidate materials (1); Correlation of organic carbon (kg t^{-1}) and relatively stable organic carbon (kg t^{-1}) of candidate materials (2).

In general terms as the OC content of a material increase so did the amount of both relatively unstable OC and relatively stable OC (Figure 6). Lines of regression linking total OC with either relatively unstable or stable OC had gradients of 0.70 and 0.68, respectively. Thus, across the 31 materials the average unstable OC proportion was 70% and the average stable OC proportion was 68%. These values do not sum to 100% because they are derived from two distinct correlation analyses.

It is important to note that many materials did not fit these general relationships. To draw attention to a few of examples: SW BC and HW BC (both biochars) had very high OC content (>800 kg t^{-1}); however, only a small proportion of this OC was relatively unstable with the majority (94 – 96 %) being relatively stable. In contrast, MHS and SBG (sawdust and brewery grain, respectively) had considerable OC loads (>400 kg t^{-1}) but virtually all of this (83 – 91%) OC was in attributed to the relatively unstable fraction.

These results make clear an important point for the constructed soil designer. Considering candidate material based on their total OC loads, while generally useful, does not inform the designer if the material will likely confer long-term carbon storage to a constructed soil. To have confidence in a *long-term carbon storage a high amount of OC alongside a large proportion of relatively stable OC will be needed*. Viewed for the opposing perspective total OC will not usefully inform how likely a material is to nourish the biology of the soil; here, the amount of relatively unstable OC will be salient.

To support the design of constructed soils the ReCon Soil project has created a ***CarbonReConer© Soil Recipe Design Tool*** (available in the toolkit archive). This tool allows the user to ascribe proportions of bulk candidate materials in a user defined recipe, and then reports back the total OC of the mixture along with loadings of the relatively unstable OC and relatively stable OC in the mixture. The data provided in Appendix A forms the basis of the design tool.

In defining a recipe for a constructed soil, the designer will also need to consider the non-carbon properties of the components/mixture. In selecting type and proportion of mineral components their particle size distribution (i.e. texture) should be considered. Texture underpins water flow and water storage in a material/mixture and influences susceptibility/resilience to compaction. In designing a constructed soil for a given end use, for example, to grow a high biodiversity meadow of native grasses and flowers: a low nutrient status, low organic matter content, free draining and a pH above neutral (> pH7) will be desirable. In this scenario the constructed soil designer will likely select sandy material (to support free drainage) and a low OC material with high pH to deliver an alkaline outcome and to minimise nutrient content in the mixture.

To support the selection of candidate materials the ReCon Soil project has developed:

- a ***CarbonReConer© Soil Recipe Design Tool.***
- 31 ***Material Cards*** that summarise the carbon properties of candidate materials and the attributes these materials could confer to a constructed soil.
- a ***Protocol for Assessment of Waste Materials for use in Reconstructed Soils***.

Material Cards, the CarbonReConer© Soil Recipe Design Tool (and manual), and the Protocol for Assessment of Waste Materials are available in the project toolkit archive.

References

ISO. (1995). ISO 10694: 1995 Soil Quality Determination of Organic and Total Carbon after Dry Combustion (Elementary Analysis).

Rao, T. R., & Sharma, A. (1998). Pyrolysis rates of biomass materials. *Energy*, *23*(11), 973-978.

Yang, H., Yan, R., Chen, H., Lee, D. H., & Zheng, C. (2007). Characteristics of hemicellulose, cellulose and lignin pyrolysis. *Fuel*, *86*(12-13), 1781-1788.

Appendix A:

Key properties of candidate materials and their proportions/masses of non-stable and relatively stable carbon (*dry matter basis unless otherwise stated*)
N=6 for density testing and N=3 for all other measurements.

Candidate material	Moisture[a]	Density[b]	OM[c]	TC[d]	TN[d]	TH[d]	C:N ratio[d]	OC[e]	Relatively unstable OC	Relatively stable OC
	%	g cm^{-3}	%	%	%	%		kg t^{-1}	kg t^{-1}	kg t^{-1}
UK green waste compost (UK GWC)	8.3 ± 0.3	0.51	39.4 ± 0.7	20.4 ± 2.0	1.5 ± 0.2	2.5 ± 0.2	14:1	193 ± 20	92 ± 10	101 ± 10
CATE compost (FR GWC)	101.1 ± 12.6	0.57	31.7 ± 2.1	19.4 ± 0.8	3.0 ± 0.3	2.3 ± 0.1	6:1	170 ± 7	125 ± 5	45 ± 3
Seed sowing compost (SSC)	11.3 ± 0.5	0.75	10.8 ± 1.3	4.4 ± 1.4	BLD[f]	0.5 ± 0.2	-	37 ± 12	17 ± 5	20 ± 7
Mature plant compost (MAPC)	12.1 ± 0.8	0.66	14.3 ± 1.9	3.6 ± 0.3	BLD[f]	0.5 ± 0.1	-	36 ± 3	33 ± 3	3 ± 0.4
Multi-purpose compost (MUPC)	19.0 ± 1.1	0.60	30.6 ± 7.5	7.2 ± 0.9	BLD[f]	0.7 ± 0.1	-	71 ± 9	68 ± 9	4 ± 1
Greenworld green waste compost (GW GWC)	48.7 ± 4.2	0.43	47.9 ± 2.3	28.2 ± 4.0	1.8 ± 0.1	3.4 ± 0.5	16:1	243 ± 36	140 ± 21	103 ± 15
Composted bark (CB)	57.0 ± 1.2	0.27	88.6 ± 0.9	44.2 ± 0.3	0.8 ± 0.1	4.2 ± 0.1	55:1	441 ± 4	211 ± 8	230 ± 10
Maurice Mason anaerobic digestate (MM AD)	15.7 ± 0.1	0.22	83.0 ± 0.3	40.9 ± 0.8	2.4 ± 0.2	5.0 ± 0.04	17:1	350 ± 31	251 ± 23	99 ± 8
Paper crumble (PC)	21.0 ± 0.2	0.74	23.5 ± 0.1	20.3 ± 0.3	0.5 ± 0.1	1.7 ± 0.1	44:1	87 ± 3	39 ± 1	47 ± 2
Hardwood oak biochar (HW BC)	6.6 ± 0.3	0.34	93.3 ± 0.3	79.2 ± 0.1	0.6 ± 0.02	1.3 ± 0.04	127:1	779 ± 10	33 ± 5	745 ± 8
Softwood BD (Cuø) biochar (SW BC)	13.6 ± 1.7	0.16	100.0 ± 1.4	78.9 ± 0.2	0.5 ± 0.1	1.3 ± 0.7	168:1	788 ± 2	52 ± 1	737 ± 1
Carbon Gold biochar (CG BD)	11.1 ± 0.2	0.62	72.8 ± 1.1	4.9 ± 2.4	0.8 ± 0.1	2.4 ± 0.1	58:1	446 ± 26	77 ± 6	368 ± 30
UK biochar (UK BC)	7.5 ± 0.2	0.52	73.5 ± 1.6	54.2 ± 3.4	1.3 ± 0.1	1.6 ± 0.1	43:1	442 ± 25	179 ± 9	263 ± 19
Factor X-charcoal dust/biochar (FXBC)	6.7 ± 0.4	0.41	76.4 ± 5.3	54.1 ± 2.3	1.2 ± 0.1	1.7 ± 0.1	45:1	387 ± 30	173 ± 23	214 ± 15
Sharp sand (SS)	2.2 ± 0.0	1.23	0.4 ± 0.1	0.4 ± 0.1	BLD[f]	BLD[f]	-	2 ± 1	1 ± 1	2 ± 1
Lignite clay (LC)	17.4 ± 0.3	0.99	27.5 ± 1.0	13.1 ± 0.9	0.3 ± 0.02	2.2 ± 0.2	46:1	105 ± 8	31 ± 3	74 ± 5
Quarry mineral sludge (QMS)	45.6 ± 2.9	1.07	4.3 ± 0.1	0.1 ± 0.02	0.04 ± 0.03	1.0 ± 0.03	2:1	1 ± 0.1	0.2 ± 0.04	1 ± 0.1
Excavated clay soil (ExS)	33.0 ± 7.1	0.83	4.0 ± 0.3	0.3 ± 0.1	0.1 ± 0.02	0.7 ± 0.1	3:1	3 ± 1	1 ± 0.3	2 ± 0.5
Treated sediment (TS)	108.0 ± 30.6	1.12	6.0 ± 0.8	6.6 ± 0.1	0.6 ± 0.1	0.7 ± 0.04	11:1	59 ± 1	15 ± 0.5	44 ± 1
Non-treated sediment (NTS)	135.0 ± 2.3	1.24	6.3 ± 0.3	6.2 ± 0.1	0.8 ± 0.2	0.7 ± 0.01	8:1	52 ± 1	12 ± 0.2	40 ± 1
Mixed hardwood sawdust (MHS)	11.3 ± 3.3	0.26	100.0 ± 3.1	46.1 ± 0.03	1.2 ± 0.1	4.2 ± 0.2	38:1	449 ± 1	374 ± 0.3	75 ± 1
Agricultural residues (compost like output) (CLO AR)	41.9 ± 1.8	0.86	14.7 ± 1.3	9.8 ± 0.9	0.6 ± 0.1	1.2 ± 0.1	16:1	85 ± 7	26 ± 4	58 ± 5
Brash chippings (BRC)	48.7 ± 5.9	0.32	58.7 ± 5.7	31.1 ± 2.1	1.2 ± 0.1	4.0 ± 0.2	26:1	278 ± 21	163 ± 17	115 ± 27
Spent brewery grain (SBG)	9.7 ± 0.1	0.51	98.2 ± 0.3	44.2 ± 0.2	3.6 ± 0.2	5.3 ± 0.1	12:1	432 ± 2	394 ± 3	38 ± 2
Coffee grounds (CG)	57.7 ± 20.4	0.45	100.0 ± 27.6	49.2 ± 0.1	3.2 ± 0.1	5.6 ± 0.04	15:1	479 ± 4	428 ± 5	51 ± 1
Used tea and tea bags (T&TB)	7.9 ± 0.2	0.18	90.4 ± 1.5	43.4 ± 0.4	3.8 ± 0.3	4.1 ± 0.1	11:1	405 ± 1	299 ± 3	106 ± 2
Sub soil peat (SSP)	163.9 ± 40.4	0.73	47.5 ± 5.3	20.6 ± 2.1	1.2 ± 0.04	2.4 ± 0.1	18:1	189 ± 20	108 ± 11	81 ± 9
Topsoil (20mm screened) (STS)	30.4 ± 0.5	1.02	8.6 ± 0.4	4.2 ± 0.3	0.3 ± 0.04	0.6 ± 0.05	12:1	35 ± 2	11 ± 1	24 ± 2
Topsoil (WH TS)	44.9 ± 3.1	0.67	30.6 ± 7.5	5.7 ± 0.4	0.4 ± 0.02	0.7 ± 0.03	16:1	51 ± 4	26 ± 3	25 ± 2
Surface horizon agricultural soil (SHS)	12.2 ± 1.3	1.13	2.3 ± 0.1	1.9 ± 0.2	0.1 ± 0.01	0.3 ± 0.03	35:1	14 ± 3	5 ± 2	8 ± 4
Deep horizon agricultural soil (DHS)	13.6 ± 0.4	1.14	3.2 ± 0.3	0.7 ± 0.1	BLD[f]	0.3 ± 0.03	-	6 ± 1	4 ± 0.2	2 ± 0.3

[a]Moisture content (N = 3) was determined by drying samples in the oven at 80°C for 2 days.
[b]Density was determined by cylinder methods under gradually increased volumes (10 to 500 ml), the gradient of the 'best fit line' was determined as density.
[c]OM: organic matter measured by loss on ignition. Samples (N = 3) were dried for 2 days (80 ˚C) and then combusted for 24 hours (450 ˚C).
[d]TC: total carbon; TN: total nitrogen; TH: total hydrogen; C:N ration: carbon:nitrogen ratio.
[e]OC: oraganic carbon.
[f]BLD: below the limit of detection.