Soil Carbon and the Woodland Carbon Code
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Introductory statement on soil carbon

Soils in the UK have different thicknesses of organic matter overlying a mineral layer or rock. The upper organic layer, containing plant and animal residues at various stages of decomposition, contains a high proportion of the carbon in the soil while there can be appreciable quantities of organic matter associated with surface and sub-surface mineral layers.

Woodland as a land use tends to have high levels of soil organic carbon which increase over time, with high inputs of decomposable material from large woody material, foliage and fine roots. However, disturbance of the soil, such as can be seen when preparing ground for woodland creation, managing the woodland for timber or during a windthrow event, can lead to greenhouse gas emissions (Read et al, 2009; Reynolds et al 2007). This is also true of soil drainage. Research suggests that following initial carbon losses from site preparation, the soil carbon will continue to accumulate over the next few decades at least (Read et al 2009). Site preparation techniques vary widely in the amount of soil disturbed and emissions of soil carbon (See Table 2). Thinning causes only a minor loss to the soil carbon stock, lasting no more than 2 years. Leaving the roots, stumps, branches and needles onsite can help minimise soil carbon losses if clearfelling (Read et al 2009).

The Woodland Carbon Code recognises that the carbon benefits associated with woodland creation are generally greatest on soils with lower organic matter content such as mineral soils and where establishment and management techniques disturb the soil as little as possible. As such, it advocates ground preparation techniques with the minimum soil disturbance necessary for successful establishment. Research is still ongoing to fully understand the changes to soil carbon as a result of land use change and land management activities. As such, the approach set out here ensures that soil carbon emissions associated with the project are not under-estimated and that any soil carbon sequestration associated with the woodland creation project is not over-estimated. This conservative approach therefore maintains the integrity of the Woodland Carbon Code with respect to soil carbon exchange.

This approach has been developed with the support of a group of soil experts from across the UK including Elena Vanguelova, Robert Matthews, Mike Perks, Bill Rayner and Colin Saunders, (Forest Research), Steve Chapman and Allan Lilly (The

James Hutton Institute), Pete Smith (University of Aberdeen), and Maurizio Mencuccini (University of Edinburgh).

Definition of organic, organo-mineral and mineral soils

A comparison of the soil classifications used in the soil surveys of England & Wales, Scotland and the Forestry Commission's own classification is given in a separate document *(see Soil Classification V1 21 July 2011)*. It identifies which soils are considered organic, organo-mineral and mineral.

Organic soils: In Scotland and Northern Ireland, organic soils are those with an organic layer of at least 50cm. In England and Wales they are recognised as having an organic layer of at least 40cm. The Forestry Commission classifies, organic soils as having an organic layer of > 45cm. These organic soils can also be known as peats in Scotland and Northern Ireland and deep peats in England and Wales.

Organo-mineral soils: In Scotland and Northern Ireland, organo-mineral soils have an organic layer of 50 cm or less, and in England and Wales 40cm or less. The Forestry Commission classifies organo-mineral soils as having organic layer from 5cm up to 45cm. These can include humus-iron podzols, peaty podzols, surface and ground water peaty gleys, peaty rankers and podzolic rankers.

Mineral soils In soil surveys across the UK, mineral soils are not defined as having an organic layer (primarily composed of decaying plant material) although they do contain an organic horizon (with higher organic content than underlying horizons). The Forestry Commission classifies mineral soils as having organic layer of less than 5cm. These can include brown earths, brown rankers and rendzinas, cultivated podzols, surface water and ground water mineral gleys.

Soil carbon in the Woodland Carbon Code

Organic soils: On some soils with a deep organic layer the magnitude of soil carbon losses due to disturbance and oxidation can be greater than carbon uptake by tree growth over the long term. For this reason, in addition to habitat and biodiversity value, the Woodland Carbon Code does not allow certification of woodland created on soils with an organic (peat) layer of more than 50 cm[1].

Organo-mineral soils: On soils with an organic layer of 50 cm or less, there are still likely to be some soil carbon losses due to disturbance for establishment and management purposes, but these are likely to be smaller. The conservative approach outlined here means projects on organo-mineral soils need to account for the loss of carbon due to establishment activities.

In future, in the case where there is minimal ongoing intervention planned (i.e. no thinning or clearfelling) the project will be able to claim some carbon sequestration over the project duration. Projects with more intensive management (e.g. thinning or clearfelling) may be able to account for soil carbon gains but will also have to account for soil carbon losses during ongoing management.

[1] Note definitions across UK. For the purposes of the Woodland Carbon Code, the decision not to allow projects on soils with an organic layer exceeding 50cm is applied consistently across the UK. Soils in England and Wales with an organic layer depth of 40-50cm will be considered alongside the organo-mineral soils for the purposes of the Woodland Carbon Code.

Mineral soils: On mineral soils where no organic layer is present, we can be fairly confident that any losses of soil carbon due to disturbance for management are likely to be minimal. Here the conservative approach only requires projects with higher impact establishment techniques to account for an initial loss of soil carbon; for low impact methods it is assumed that there is no initial loss. On arable soils where there is minimal ongoing intervention planned (i.e. no thinning or clearfelling) the project can claim some carbon sequestration over the project duration.

In future, projects on arable land proposing more intensive woodland management (thinning or clearfelling) may be able to account for soil carbon gains but will also have to account for soil carbon losses during ongoing management. Projects on grassland/pasture will likewise have to account for losses as well as gains to soil carbon.

Soil carbon content at the start of the project

Unless the project has undertaken specific soil carbon assessment prior to tree planting, then we will assume that the soil carbon content at the site at the start of the project can be derived from looking at the closest land use type from Table 6 of Bradley *et al* (2005) (converted to tCO_2e/ha). Note we recognise these figures are the mean mass of soil carbon across each land use and country, and in reality there is a large variation. At present, this is the only dataset sourced that has been developed using consistent protocols for the UK as a whole.

Table 1: Soil Carbon (tCO_2/ha) for various landuse types across the UK
(Adapted from Bradley et al 2005, Table 6)

UNITS = tonne CO2e/ha			Landuse			
	Depth		Seminatural	Pasture	Arable	Woodland
England	0–30	cm	440	293	257	367
	30–100	cm	623	183	183	257
	0–100	**cm**	**1063**	**477**	**440**	**623**
Scotland	0–30	cm	587	587	440	623
	30–100	cm	623	257	147	623
	0–100	**cm**	**1210**	**843**	**550**	**1210**
Wales	0–30	cm	403	330	257	440
	30–100	cm	440	183	147	293
	0–100	**cm**	**843**	**513**	**403**	**733**
NI	0–30	cm	697	477	367	660
	30–100	cm	733	293	183	697
	0–100	**cm**	**1430**	**770**	**550**	**1357**

Note: **Seminatural** includes seminatural vegetation and grassland that receives no management
Pasture includes permanent managed grassland
Arable includes arable and rotational grassland
Woodland includes broadleaved and conifer woodland

Soil carbon in the 'baseline scenario'

Projects under the code have to define a baseline scenario, which assumes that the current land use would continue if the project didn't go ahead. They need to predict what changes would have occurred to the soil carbon in the absence of the project going ahead. A conservative approach to the baseline scenario is taken in which ongoing emissions are not accounted for. In addition, given that gains to soil carbon in the non-wooded baseline scenario over the project duration are not likely to be significant (i.e. <5% of the project carbon sequestration), we will assume that there is no change over time to soil carbon in the baseline scenario.

BOX 1: **CDM methodology for estimation of change in SOC stocks due to implementation of A/R CDM projects works as follows:**

It's applicable to **non-organic, non-wetland sites where litter remains onsite and any ploughing/scarification is done in accordance with best practice**.
Stratify project land by soil type, current land use (grassland, long-term cropland, short-term cropland, improved/moderately degraded/severely degraded grassland), management activity (full/reduced/no till), inputs (residues, manure, fertiliser), % area to be ploughed/ripped/scarified.
For each strata, **initial carbon stock** = f (land use, management activity, inputs)* SOC stock under native vegetation (=woodland) for mineral soils, 0-30cm depth. (5 different soil types for 9 climatic zones globally). The factors are calculated for SOC stock change over 20 years of such use.
Initial carbon loss, applied in year 1: Depending on intensity of site prep:
Where > 10% of a strata is ploughed/scarified/ripped then carbon loss over first 5 years from site prep is 10% of the initial carbon stock.
Where <= 10% of strata is ploughed/scarified/ripped then c loss is ZERO.
Subsequent Carbon gain, applied in years 1 to 20: Carbon gain each year is 1/20(SOC under native vegetation MINUS what you're left with onsite after ground prep). Carbon can accumulate no faster than 0.8tC/ha/yr (2.9tCO2e/ha/yr).

So basically you work out how degraded the soil is from seminatural/woodland SOC, take off another 10% in year 1 (if ploughing) and then say that SOC can all accumulate again to the amount of SOC under seminatural/woodland over the next 20 years, subject to a maximum rate of 2.9tCO2/ha. It doesn't allow accumulation after 20 years if you haven't got as far as the seminatural/woodland SOC reference level by that year.

Note CDM projects tend to be shorter timescale than Woodland Carbon Code projects

Changes to soil carbon: Organo-mineral soil

Research recognises that there can be initial losses to soil carbon on organo-mineral soils, but that depending on the intensity of the ground preparation and ongoing management, there can be subsequent gains to soil carbon as woodlands grow and mature. Projects should account for soil carbon according to the following simple methodology, similar in outline to the CDM methodology for soil carbon accounting (Summarised in box 1), but with values based on UK data. This method is conservative in that:

- initial soil carbon losses should be accounted for. This includes losses due to soil disturbance from ground preparation as well as oxidation due to the soil drying out as the trees grow,
- initial soil carbon losses are accounted for in year 1 of the project whereas in reality the soil carbon might be lost over a decade or more.
- the amount of soil carbon assumed lost is at the high end of what research to date tends to show.

If any other ground preparation is undertaken which is not specified here then this should be accounted for separately following advice from the Forestry Commission:

Projects should either

- ***follow the methodology set out below, or***
- ***undertake a soil carbon assessment prior to tree planting with repeat assessments as the project progresses***

1. If required, stratify the site by current land use and site preparation techniques (see Tables 1 and 2).
2. Establish soil carbon stock at start of project from Bradley *et al* (2005) (See Table 1) in absence of any better site-based information (by strata if required and for the whole site).
3. Take off a **proportion of topsoil carbon (0-30cm) in year 1** for establishment, dependent upon establishment method (See Table 2) by strata (if required) and for the whole site:

0% of 0-30cm soil carbon:	Hand Screefing
5% of 0-30cm soil carbon:	Hand Turfing and Mounding
10% of 0-30cm soil carbon:	Forestry Ploughing (Shallow Turfing) and Scarifying
20% of 0-30cm soil carbon:	Forestry Ploughing (Deep Turfing and Tine)
40% of 0-30cm soil carbon:	Agricultural Ploughing

3. Further research in the next 2-3 years will allow us to develop more reliable figures for rates of soil carbon accumulation. Results of this research will be used in the next Woodland Carbon Code update on soil carbon. Projects will be able to update their soil carbon estimates at the first verification, based this research and update.

Table 2 The soil disturbance of site preparation treatments typical in upland UK forestry (Bill Rayner, Colin Saunders (*pers comm.*) after Taylor (1970), Tabbush (1998), Worrel (1996))

Method of Site Preparation	Volume disturbed m3/ha	% of Topsoil (0-30cm) disturbed	Organomineral: % Topsoil carbon (0-30cm) to subtract	Mineral: % Topsoil carbon (0-30cm) to subtract
Hand screefing	Negligible		0%	0%
Hand turfing / drains	60	2.00%	5%	0%
Drains at 250m/ha - 360° excavator with a draining bucket	134	4.47%	5%	0%
Drain mounding – 360° excavator with a drainage bucket	246	8.20%	5%	0%
Trench mounding + drains @250m/ha - 360° excavator	380	12.67%	5%	0%
Turfing – Double throw rotary mouldboard, shallow, plough	560	18.67%	10%	2%
Patch scarification	630	21.00%	10%	2%
Turfing – Double throw mouldboard, shallow, plough	710	23.67%	10%	2%
Disc trencher/scarifier	840	28.00%	10%	2%
Turfing – Double throw mouldboard, deep, plough	1,030	34.33%	20%	5%
Turfing – Single throw mouldboard plough	1,030	34.33%	20%	5%
Tine – Double throw mouldboard plough	1,430	47.67%	20%	5%
Tine – Single throw mouldboard plough	1,575	52.50%	20%	5%
Agricultural ploughing	2,500	83.33%	40%	10%

NOTE: Cultivation is not an exact science, as individual implements with individual operators on specific sites will all create differing degrees of disturbance. Assumptions have been made about the use of each implement to quantify the potential volumes of soil/peat which may be disturbed to prepare a site prior to planting with trees. This includes assuming site preparation as per the Forestry Commission's Operational Guidance Booklet 4 so as to create 2,900 planting positions per hectare (ha) and achieve an established tree stocking density of 2,700 trees per ha.

Changes to soil carbon: Mineral soil

Research suggests that there are unlikely to be large initial losses of soil carbon on mineral soils. In fact on arable soil for projects managed though minimum intervention research shows that carbon can accumulate at rates between 0.3tC/ha/yr (1.1tCO_2/ha/yr) initially, slowing in later years (McKay (2011)). Results for pasture/grassland on mineral soils are less clear. The methodology set out below is conservative in that:

- initial soil carbon losses should be accounted for. This includes losses due to soil disturbance from ground preparation as well as oxidation due to the soil drying out as the trees grow,
- initial soil carbon losses are accounted for in year 1 of the project whereas in reality the soil carbon might be lost over a decade or more.
- the amount of soil carbon assumed lost is at the high end of what research to date indicates.
- the amount of soil carbon predicted to accumulate subsequent to initial losses is at the low end of what research to date shows.

Projects should either:

- ***follow the methodology set out below, or***
- ***undertake a soil carbon assessment prior to tree planting with repeat assessments as the project progresses***

1. If required, stratify the site by current land use and site preparation techniques (see Table 1 and 2).
2. Establish soil carbon stock at start of project from Bradley *et al* (2005) (See Table 1) in absence of any better site-based information (by strata if required and for the whole site).
3. Take off a **proportion of topsoil carbon (0-30cm) in year 1** for establishment, dependent upon establishment method (See Table 2) by strata (if required) and for the whole site):

0% of 0-30cm soil carbon:	Hand Screefing, Hand Turfing and Mounding
2% of 0-30cm soil carbon:	Forestry Ploughing (Shallow Turfing) and Scarifying
5% of 0-30cm soil carbon:	Forestry Ploughing (Deep Turfing and Tine)
10% of 0-30cm soil carbon:	Agricultural Ploughing

4. Projects involving woodland managed through minimum intervention can account for soil C accumulation at the following rates:

- For project sites previously under arable or rotational grass use and now managed as minimum intervention woodland: Assume sequestration/accumulation to soil carbon at 0.15tC/ha/yr (0.55tCO_2/ha/yr) in years 1 to 50 and 0.1tC/ha (0.37tCO_2/ha/yr) thereafter until the end of the project. This is a conservative estimate based on the slower rates of soil carbon accumulation summarised in McKay (2011) Tables 2 and 3, reproduced in Appendix 1.

- For project sites previously under permanent pasture/grassland use and now managed as minimum intervention woodland, research is less clear. There is definitely a drop in soil carbon in initial years followed by increases after a decade or more. In the short term, the initial losses might cancel out any gain so it is assumed that there will be no change in soil carbon over time following the initial establishment phase.

For land previously both under arable and pasture where the subsequent woodland management will involve thinning or clearfelling operations likely to disturb the soil, further research is underway which will help quantify the changes to soil carbon. The second release of soil carbon figures will also allow some accumulation in other previous land use or ongoing woodland management scenarios.

Future developments

- We will include the Northern Ireland Soil Survey in the comparison of soil classifications.
- For Scotland more soil-specific carbon stock information may be available from: http://sifss.macaulay.ac.uk/.
- We will update Table 1 (Soil carbon by landuse type) with information by soil grouping (Organic, Organo-mineral and Mineral) or where possible by soil type to increase the accuracy of these predictions.
- Ongoing research will help us better understand the changes to soil carbon due to woodland creation and management.
- We will update the soil carbon methodology within 2 years using results of ongoing research. This will allow us to say with more certainty both the amount of soil carbon lost on woodland establishment as well as the rate of accumulation of soil carbon as the woodland grows and matures.
- We will establish a soil carbon assessment protocol to enable projects to consistently assess the soil carbon content of their soil.

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Appendix 1: Tables 2 and 3 from Short Rotation Forestry Review (McKay 2011)

Table 2. Changes of soil carbon under SRC and SRF plantations.

SRC/SRF/ species planted	Previous land use	Soil depth (cm)	Time span (years)	Soil C (kg C ha^{-1} y^{-1} or %)	Reference
SRC Poplar (USA)	Agriculture	100	12-18	1630 (kg C ha^{-1})	Hansen, 1993
SRC Poplar (USA)	Agriculture	0-25; 0-100	6-15	No change; no change	Grigal and Berguson, 1998
SRC Willow (USA)	Grass/scrub land	0-60	4	No change; no change	Ulzen-Appiah, Briggs et al, 2000
Mixed coppice of (Germany)	Agriculture	0-10	7-9	100-555 (kg C ha^{-1}) gain	Jug, Makeschin et al, 1999
Poplar, Aspen and Willow	Agriculture	10-30	7-9	0-555 (kg C ha^{-1}) loss	Jug, Makeschin et al, 1999
Oak plantation (Denmark)	pasture	0-25 mineral only		~ 420 (kg C ha^{-1}) loss	Vesterdal et al, 2002
Oak plantation (Denmark)	pasture	' min+ forest floor		~ 333 (kg C ha^{-1}) loss	Vesterdal et al, 2002
Plantation	Pasture	meta analysis		10% loss	Guo and Gifford, 2002
Plantation	Native forest	meta analysis		13% loss	Guo and Gifford, 2002
Plantation	Arable	meta analysis		18% gain	Guo and Gifford, 2002
Secondary forest	Arable	meta analysis		53% gain	Guo and Gifford, 2002
Eucalyptus nitens (Tasmania, Australia)	Pasture	30	0-10	~ 200 (kg C ha^{-1}) loss(-1.99%pa)	Paul et al 2003[1]
Eucalyptus nitens (Tasmania, Australia)	Pasture	30	10-40	~30 (kg C ha^{-1}) inc. (+0.82%pa)	Paul et al 2003[1]
Eucalyptus globulus (Victoria, Australia)	Pasture	30	0-10	~ 220 (kg C ha^{-1}) loss(-2.08%pa)	Paul et al 2003
Eucalyptus globulus (Victoria, Australia)	Pasture	30	10-40	~100 (kg C ha^{-1}) inc (+0.39%pa)	Paul et al 2003
Eucalyptus globulus (SW Australia)	Pasture	30	0-10	~20 (kg C ha^{-1}) loss(-0.96%pa)	Paul et al 2003
Eucalyptus globulus (SW Australia)	Pasture	30	10-40	~200 (kg C ha^{-1}) inc (+1.80%pa)	Paul et al 2003

[1] case studies with partly modelled start values

Table 3. Rates of soil carbon sequestration after re-establishment of deciduous forest on agricultural land.

Forest Ecosystem	Previous land use	Years since land use change	Soil depth (cm)	Soil C rate (kg C ha^{-1} y^{-1})	Reference
Old field succession to hard woods (US)	Arable	10	10	151	Zak, Grugal et al, 1990
Old field sucession to mixed oak (US)	Arable	>250	15	94	Robertson and Vitousek, 1981
Oldfield sucession to hardwoods (US)	Arable	>100	10	116	Robertson and Tiedje, 1984
Abandoned field to mixed forest (US)	Arable	66	43	22	Hamburg 1984
Natural oak forest sucession, Broadbalk (UK)	Arable	100	30	561	Jenkinson, 1990
Natural oak forest sucession, Geescroft (UK)	Arable	102	30	426	Poulton, 1996
Planted hardwood, West tofts (UK)	Heathland	21	70	~47.6	Ovington, 1956
Planted hardwood, Bedgebury (UK)	Hazel coppice/standards	20	70	(v.high >700)	Ovington, 1957
Planted hardwoo, Abbot wood (UK)	Mixed oak wood	45	70	~666	Ovington, 1958
Planted oak, Alice Holt (UK)	Pasture woodland	80	15	116	Pitman and Benham FR