



Supplement of

Physical protection of soil carbon stocks under regenerative agriculture

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Supporting Information

Table S1: A glossary of terms for the different soil carbon types and soil aggregate fractions discussed in the investigation, and additional details as to their role in the study and method of determination.

Term	Refined Definition / Description	Role in the Study	Measurement Method
Bulk Soil	The 2mm sieved but unseparated soil matrix including all mineral, organic, and particulate components, used as a baseline for comparison.	Acts as a reference point for evaluating changes in aggregate structure and carbon content across treatments.	Collected using a Dent soil corer (0–7.5 cm), oven-dried at 40°C, then sieved (2mm) and either then milled for elemental and thermal analysis or separated into soil fractions following fractionation methods.
Non-Water Stable Aggregates (NWSA)	Soil particles that disaggregate rapidly upon wetting, indicating low aggregate cohesion and stability.	Proxy for soil degradation and potential for carbon loss. Decreasing NWSA indicates improved soil structural integrity.	Generated via capillary-wetting wet sieving method; particles <63µm transferred after submersion/agitation were classified as NWSA.
Sand Fraction	Coarse mineral portion (>63µm, <2mm) remaining after removal of NWSA aggregates.	Used to normalise carbon pools and control for large particle inorganic mineral content; not influenced by land management.	Separated chemically from WSA using sodium hexametaphosphate (0.02 M) post sieving.
Water Stable Aggregates (WSA)	Aggregates that maintain their structure under wet conditions; indicative of biological and physicogenic stability.	Key indicator of carbon protection potential; increased WSA signals enhanced physical carbon protection.	Derived by subtracting NWSA and sand fractions from total soil mass; verified by agitation in deionised water and chemical disaggregation.
Soil Carbon (Total SOC)	Combined pool of all organic carbon in the soil, including labile, recalcitrant, and aggregate-associated forms.	Central indicator of soil health, carbon sequestration capacity, and management impact.	Measured via CHN elemental analyser (Exeter CHNS CE440) on milled bulk soil samples (20 mg).
Thermally Labile Carbon	Thermally labile organic carbon that is easily decomposed by microbial activity or oxidation; short residence time.	Indicator of short term carbon gains and rapid changes in soil carbon stocks. Highlighted as an unstable form of soil carbon.	Identified by mass loss during thermogravimetry between 125–375°C (Mettler Toledo TGA/DSC 1) under inert atmosphere.
Thermally Recalcitrant Carbon	Organic carbon highly resistant to microbial and oxidative degradation; includes	Reflects long-term sequestration potential; considered inherently	Identified by mass loss during thermogravimetry between

	lignin-rich resistant material.	stable regardless of aggregate association.	375–700°C; stability confirmed via combustion profiles.
NWSA Carbon	Portion of soil carbon (Total SOC) located within or bound to non-water stable aggregates.	Considered potentially vulnerable carbon; reduction in this pool suggests progress in carbon stabilisation.	Measured via CHN elemental analyser (Exeter CHNS CE440) of NWSA fraction post wet-sieving and drying; normalised to bulk density and soil depth.
WSA Carbon	Portion of soil carbon (Total SOC) contained within or protected by water-stable aggregates; physically inaccessible to microbes and oxidation.	Key form of physically protected carbon; increasing this pool shows successful long term carbon sequestration potential.	Derived by subtracting NWSA and sand fractions associated carbon content from fractional soil mass; verified by agitation in deionised water and chemical disaggregation.
Occluded Carbon	Carbon that is occluded (physically protected by encapsulated within soil aggregates), limiting microbial and oxidative degradation, and providing protected stability to soil carbon.	Central focus of the study; defines physically “stabilised” carbon stocks and can include labile carbon alongside recalcitrant forms, where physical protection and occlusion are conferred to the carbon.	Inferred by combining WSA-associated labile carbon + total recalcitrant carbon, quantified by TGA and fractionation.
Unstabilised Carbon	Easily accessible, unprotected labile carbon not associated with stable aggregates.	Represents the fraction of carbon most prone to loss during tillage or disturbance, or through oxidative or biogenic decay; indicator of carbon vulnerability.	Derived by subtracting occluded carbon from total labile carbon.

Table S2: Winter and Summer cover crop seed mix information for proportions and quantities of seed applied to the alleyways between blackcurrant crops during the winter and summer months.

Winter Cover Crop			Summer Cover Crop		
Kg Product	Seed	%	Kg Product	Seed	%
7.3	Forage Rye	60.8	7.5	Buckwheat	37.5
3.5	Early English Vetch	29.2	4.5	Linseed	22.5
0.05	Crimson Clover	0.4	5	Spring Vetch	25
0.01	Paradana Balansa Clover	0.1	1	Sunflower	5
0.5	Fodder Radish	4.2	0.6	Crimson Clover	3
0.3	Forage Rape	2.5	1	Smart Radish	5
0.04	Phacelia	0.3	0.4	Phacelia	2
0.3	Brown Mustard	2.5			

Table S3: Soil texture classification, stoniness and relative proportion of sand, Non-Water Stable Aggregates (NWSA) and Water-Stable Aggregates (WSA) (%) (n=5) of alley (white) and bush (grey) regimes with increasing years of establishment. Error represents $\pm$ 1SD. For a given regime (alley or bush) dissimilar lower-case letters indicate significant ($p \leq 0.05$) differences across the timeseries. At a given timepoint, the * indicates a significant difference ($p \leq 0.05$), between the alley and bush regimes, ** indicates a significant difference ($p \leq 0.01$), between the alley and bush regimes.

Field Site	Sand %	NWSA %	WSA %	Sample Stoniness %	Soil Texture Classification
Control Alley	66.5 $\pm$ 1.7 a	27.6 $\pm$ 1.8 a	5.8 $\pm$ 0.7 a	8 $\pm$ 3 a	Sandy Loam
Control Bush	66.5 $\pm$ 1.7 a	27.6 $\pm$ 1.8 a	5.8 $\pm$ 0.7 a	8 $\pm$ 3 a	Sandy Loam
Blackcurrants Year 1 Alley	74.4 $\pm$ 1.2 b	16.5 $\pm$ 1.0 b	9.2 $\pm$ 1.0 ab	10 $\pm$ 2 a	Sandy Loam
Blackcurrants Year 1 Bush	76.4 $\pm$ 2.8 b	15.2 $\pm$ 1.3 c	8.5 $\pm$ 3.9 ab	10 $\pm$ 5 a	Sandy Loam
Blackcurrants Year 3 Alley	76.5 $\pm$ 3.1 b	15.6 $\pm$ 1.0 b	7.8 $\pm$ 2.8 ab	22 $\pm$ 2 b	Sandy Loam
Blackcurrants Year 3 Bush	77.4 $\pm$ 1.9 b	17.1 $\pm$ 2.0 bc	5.4 $\pm$ 2.2 a	27 $\pm$ 3 c	Sandy Loam
Blackcurrants Year 5 Alley	73.8 $\pm$ 3.1 b	15.9 $\pm$ 1.4 b **	10.3 $\pm$ 2.5 b	24 $\pm$ 5 b	Sandy Loam
Blackcurrants Year 5 Bush	70.2 $\pm$ 2.9 a	18.8 $\pm$ 0.9 bc **	11.0 $\pm$ 2.2 bc	18 $\pm$ 1 b	Sandy Loam
Blackcurrants Year 7 Alley	71.4 $\pm$ 2.6 ab	12.6 $\pm$ 1.6 c **	16.0 $\pm$ 1.2 c	17 $\pm$ 3 a	Sandy Loam
Blackcurrants Year 7 Bush	69.5 $\pm$ 1.9 a	16.1 $\pm$ 0.8 bc **	14.4 $\pm$ 1.7 c	17 $\pm$ 2 ab	Sandy Loam

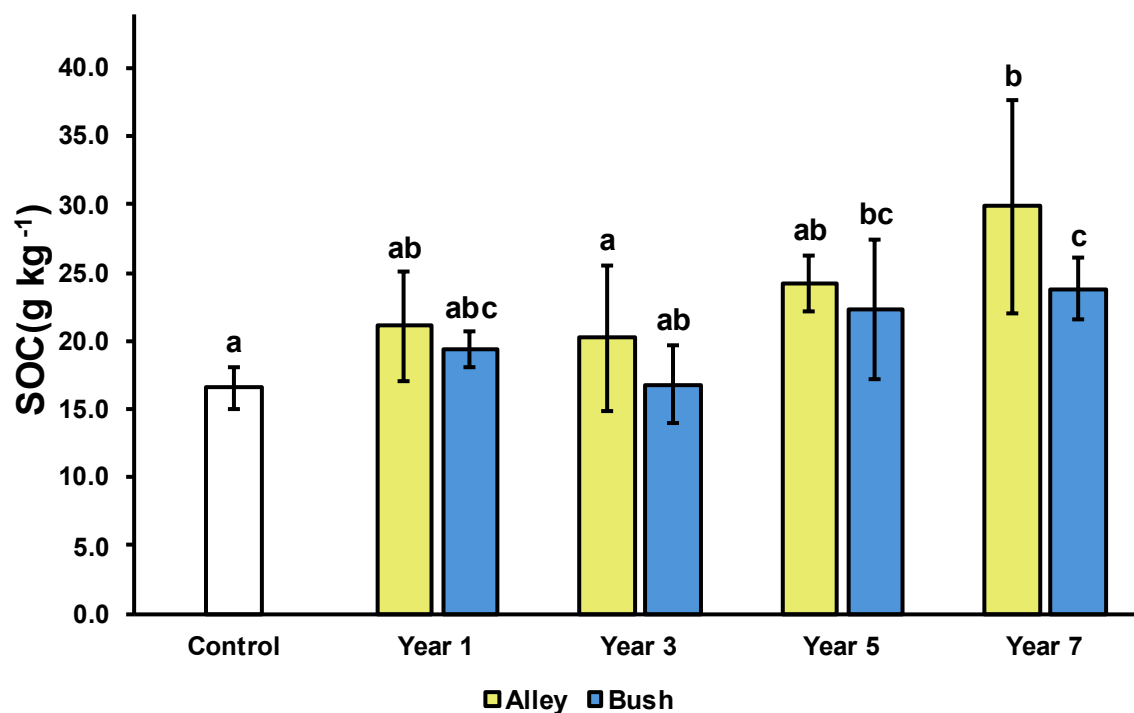


Figure S1: Soil Organic Carbon (SOC) (n=5) of alley (yellow) and bush (blue) regimes with increasing years of establishment. Error bars represent $\pm 1SD$. For a given regime (alley or bush) dissimilar lower-case letters indicate significant ($p \leq 0.05$) differences across the timeseries. At a given timepoint, * indicates a significant difference ($p < 0.05$) between the alley and bush regimes.

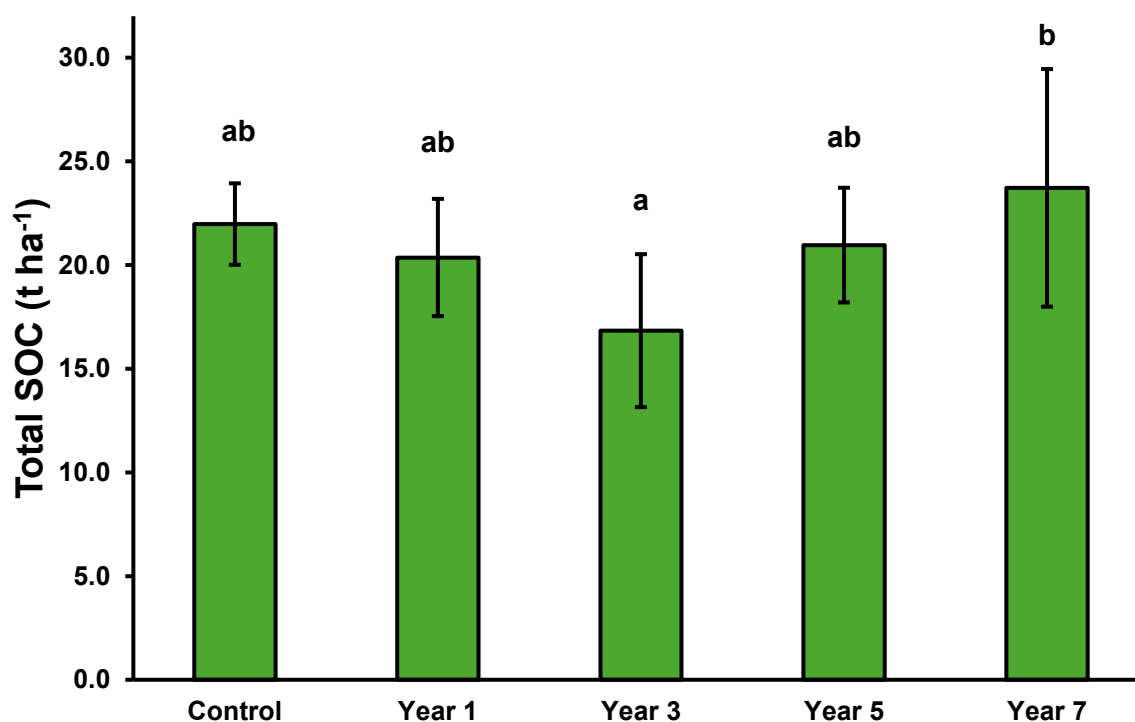


Figure S2: Total carbon field stocks (n=5), Error bars represent $\pm 1SD$. Dissimilar lower-case letters indicate significant ($p \leq 0.05$) differences across the timeseries