Bio4Ag Toolbox Indicators: soil carbon and structure

Background

Soil structure is determined largely by soil type, level of disturbance and organic matter content. Reduced tillage, organic matter inputs from plants (dead plant material and root exudates), and organic matter amendments (e.g. compost) reduce soil strength, improve soil aggregate stability and increase pore size diversity. Improved soil structure is therefore critical in minimising losses through erosion, run-off and leaching. Drainage and water holding capacity are also increased, lessening risk of waterlogging and drought. Soil conditions (temperature and moisture) are therefore better for root growth, particularly for winter cover crops and autumn sown cereals. Accumulating SOC not only benefits soil structure but increases resources for soil organisms, stimulating microbial activity and increasing rates of nitrification. Conversion of ammonia to plant available nitrate contributes to maintaining crop productivity with less reliance on mineral fertiliser.

Integrated cropping strategies

At the Centre for Sustainable Cropping, we aim to design a cropping system that can maintain yields with less reliance on agrochemical inputs, by combining management options to simultaneously promote soil health, crop fitness and biodiversity. Management options to improve soil health include a combination of reduced tillage, compost amendments and cover cropping. The soil is disturbed only one year in six for potato planting and harvest. Winter wheat is sown into the disturbed soil following potatoes, but the remaining crops in the rotation (winter barley, oilseed, beans and spring barley) are direct drilled. This minimises soil disturbance in five years of the six and provides the opportunity in the potato year to deal with any weed control and compaction issues. Organic matter amendments include green waste municipal compost from Dundee City Council applied at 35 t ha^{-1} yr^{-1} for the first rotation to create a treatment difference between the integrated and conventional systems, then reduced to a more realistic 10 t ha^{-1} yr^{-1} in the second rotation. Due to supply issues, applications are now at 5 t ha^{-1} yr^{-1} and we are monitoring soil carbon to check that SOC can be maintained at this input rate. Rye and mixed species cover crops are sown immediately after harvest prior to spring crop sowing to provide green cover over winter, helping to retain soil and nutrients and providing organic matter inputs from DOM and root exudates.

Results from the CSC

Soil carbon content was measured from 350 soil samples collected in March each year (2012-2022). Integrated soils had a significantly higher carbon content, averaging 3.4% in the integrated treatments compared to 2.5% under standard practice across all six fields ($p<0.001$, Kruskal-Wallis H statistic = 38.9, based on a mean rank of 80.3 (integrated) and 40.7 (conventional)).

Another indicator of soil physical structure is aggregate stability. The proportion of water stable aggregates was greater in the integrated soils (0.67) compared to conventional (0.53). This suggests that the integrated soils are less vulnerable to erosion than conventional soils which are ploughed annually and do not receive additional organic matter amendments.

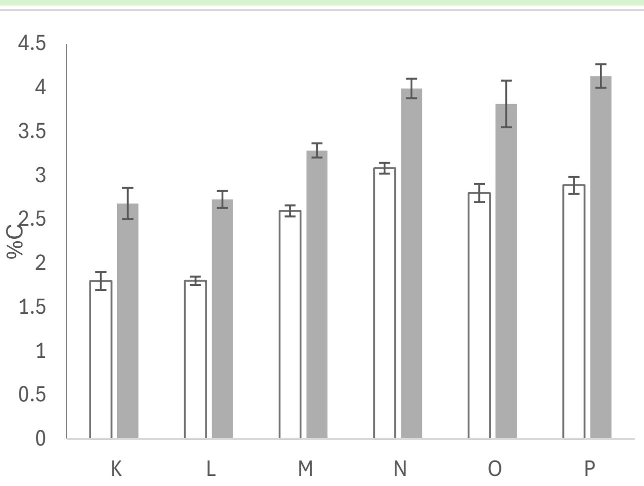

Figure 1. Soil %C in the conventional (open bars) and integrated (shaded bars) crop systems in the 6 fields (K-P) of the CSC platform.

Contact: cathy.hawes@hutton.ac.uk

How to measure soil structure

Soil collection. Soil carbon and aggregate stability are good indicators of soil structure and can be measured from the same soil samples, collected and processed as follows:

- Using a trowel, take 20 soil samples of approx. 500g each in a W-pattern across the whole field. Place each sample in a bag labelled with the field name and sample ID number (1-20).
- Sieve each sample by shaking through an 8mm sieve and discard the soil that does not fall through (stones and aggregates >8mm).
- Put the sieved soil through a 2mm sieve, again by shaking only (don't push the soil through). Place the soil that remains on top of the sieve back into the sample bag. Use this soil, comprising aggregates of 2-8mm diameter, for testing aggregate stability.
- Use the finest sieved soil (<2mm aggregates) to measure soil carbon.

Soil Carbon. Measuring soil organic matter (SOM) content is reasonably straightforward but requires access to an accurate balance and a muffle furnace.

- Weigh each sample of 2mm sieved soil and dry in an oven at 70°C for 48 hrs or until there is no further loss in weight. This will give the soil moisture content at the time of sampling.
- Using a pestle and mortar, crush the dried soil from each sample into a fine powder.
- Sub-sample approximately 5g of ground soil and record the exact weight to 3 decimal places.
- Heat in a muffle furnace at 450°C for 4 hours and then re-weigh each sample.
- The difference in weight before and after burning is called Loss on Ignition (LOI) and is a measure of soil organic matter (SOM). LOI can be converted roughly to %C using the formula: $0.513 \times LOI - (0.047 \times \%Clay - 0.00025 \times \%Clay^2)$ (Jensen et al. 2018).

Aggregate stability. This simple test measures the proportion of 2-8mm aggregates in a soil sample that remain intact when the sample is submerged in water. The greater the proportion of stable aggregates, the better the structure of the soil and the lower the risk of soil erosion.

- Place each 2-8mm aggregate sample in a foil tray and leave at room temperature to air dry for 1 week.
- Take approximately 5g from each sample and record the exact weight.
- Place the sample in a mesh suspended in a 250 ml jar of water labelled A (plus sample number) and agitate the sieve for 3 mins.
- Lift the mesh out of the water. Hold above the mesh above the jar for a few seconds to allow water to drain and put the jar of water containing the disintegrated soil to one side. These are your unstable aggregates that are dispersed on immersion in water.
- Fill a second jar, labelled B (plus sample number) with 250ml water and lower the remaining soil on the sieve into the water. Break up any aggregates and agitate until all the soil is dispersed in the water leaving only vegetative material and rocks. This is the stable aggregate fraction of your sample.
- Place both jars of water/dissolved soil from each sample into an oven at 110 °C for 24 hrs to evaporate off the water and dry the soil.
- Weigh the dried soil and divide the weight (A or B) by the total weight (A+B) to give the fraction of the soil sample made up of unstable (A) and stable (B) aggregates.

Useful links

- Emerson WW. (1995) Water-retention, organic-c and soil texture. Australian Journal of Soil Research 33: 241–51.
- Hawes, C., Iannetta, P.P.M., Squire, G.R. (2021). Agroecological practices for whole system sustainability. CAB Reviews, 16, no. 005.https://doi.org/10.1079/PAVSNNR202116005
- Jensen, J.L., Christensen, B.T., Schjonning, P., Watts, C.W., Munkholm, L.J. (2018) Converting loss on ignition to organic carbon content in arable topsoil: pitfalls and proposed procedure. European Journal of Soil Science, doi: 10.1111/ejss.12558
- Mueller L, Shepherd G, Schindler U, Ball BC, Munkholm LJ, Hennings V, et al. (2013) Evaluation of soil structure in the framework of an overall soil quality rating. Soil and Tillage Research127: 74–84
- Squire, G.R., Young, M., Ford, L., Banks, G., Hawes, C. (2020) Defining Targets for Reversing Declines of Soil Carbon in High-Intensity Arable Cropping. Agronomy, 10(7). 973 https://www.mdpi.com/2073-4395/10/7/973/htm
- https://csc.hutton.ac.uk
- https://csc.hutton.ac.uk/resource/Handbook_of_indicators_v1.pdf
- https://ahdb.org.uk/knowledge-library/how-to-assess-soil-structure
- https://www.fas.scot/downloads/practical-guide-assess-your-soil-structure/

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