Increasing soil organic carbon with nutrient application: exploring the concept in the laboratory

Dr Susan Orgill (NSW DPI, Wagga Wagga); **Dr Jason Condon** (Charles Sturt University, Wagga Wagga); **Dr Clive Kirkby** (CSIRO, Canberra); **Beverley Orchard, Dr Mark Conyers** (NSW DPI, Wagga Wagga); **Dr Richard Greene** (Australian National University, ACT); **Dr Brian Murphy** (NSW Office of Environment and Heritage, Cowra)

Key findings

- Organic carbon accumulation in soil did not approach an upper limit.
- Increases in organic carbon accumulation were due to accumulated microbial detritus (i.e. dead microorganisms and microbial products).
- Soil with the lowest organic carbon concentration at the start of the experiment accumulated the greatest mass of stable organic carbon.
- Nutrients applied based on humus nutrient ratios promoted organic carbon stabilisation in soil.

Introduction

Identifying soil with a large potential to accumulate organic carbon (OC) could maximise the mitigation benefits of carbon (C) sequestration and help producers decide if they should prioritise resources to achieve increases in soil OC. The purpose of this laboratory-based incubation experiment was to determine if an upper limit to OC accumulation in soil was approached with increasing C input in basalt- and granite-derived soils.

Site and experiment details

Site

Six permanent pasture sites, three with basalt-derived soil and three with granite-derived soil, were identified as having the highest OC concentration for their parent material class from a field survey in the Monaro region in south-eastern Australia (Orgill et al. 2014). Soil characteristics are presented in Table 1.

Table 1. Mean soil characteristics including soil type (Australian soil classification; ASC), dominant mineralogy and particle size.

Soil type	ASC, mineralogy and particle size	OC (%)	BD (g/cm^3)
Basalt-derived	Dermosol: smectite with >44% clay-sized particles		
0–0.10 m		6.25	0.88
0.40–0.50 m		2.10	1.57
Granite-derived	Kurosol: quartz with >46% sand-sized particles, and increasing clay (mainly kaolin) in subsoil		
0–0.10 m		3.26	0.85
0.40–0.50 m		0.04	1.58

Experimental design and treatments

Two soil layers (0–0.10 m and 0.40–0.50 m) were sampled from each of the six sites for this experiment. The treatment and measurement schedule for this experiment is provided in Figure 1.

Soil samples were incubated at 25 °C for up to 146 days, with soil moisture maintained at 70% field capacity. The experiment consisted of three soil incubation cycles, with four treatments applied at the start of each cycle:

1. soil only (control)
2. soil and nutrients only (nutrients)
3. high organic matter (OM) and nutrients (approximating a field equivalent of 12.4 t DM/ha or 2 years pasture growth; HOMN)
4. very high OM and nutrients (31.1 t DM/ha or 5 years pasture growth; VHOMN).

At the beginning of cycle one ^{13}C-labelled OM was applied. Nutrient application rates were calculated using the concentration of nutrients required for 30% efficiency in retaining C from the applied OM and based on the nutrient ratios of humus reported in the literature, that is carbon (C; 10): nitrogen (N; 0.83): phosphorus (P; 0.20): sulphur (S; 0.14) (Kirkby et al. 2011). The experiment was designed as a four replicate split-plot design with cycle randomised to main plots within a replicate, and treatment by soil sample randomised to sub-plots (jars) within main plots.

At the conclusion of the incubation cycle, soil samples were collected and oven dried at 40 °C. Dried samples were gently hand ground using a mortar and pestle, sieved to <2 mm and any remaining recognisable plant material (i.e. undecomposed OM) that was approximately 0.4–2 mm was removed.

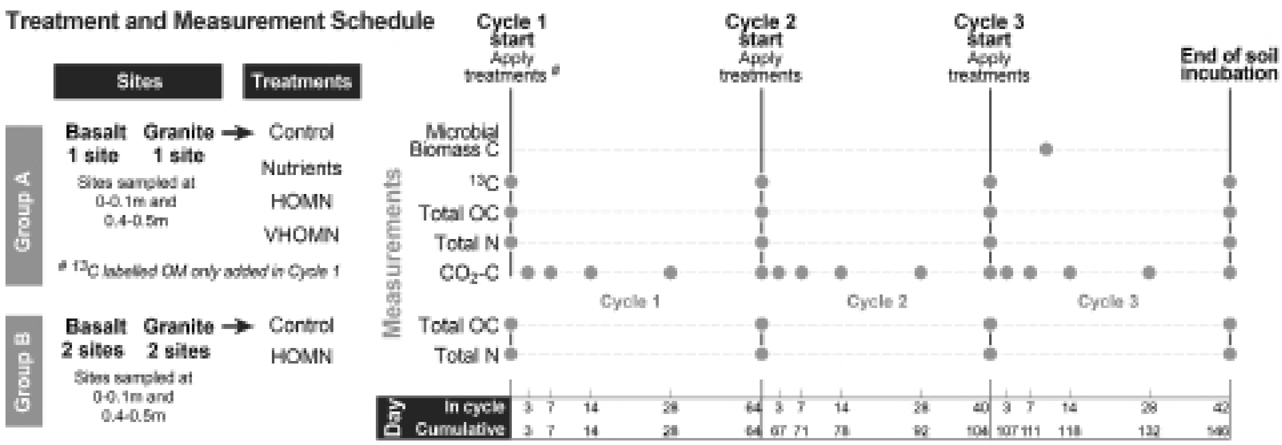

Figure 1. Schematic representation of the soil incubation experiment, including: sites (6), parent material (basalt and granite), soil depth (0–0.10 m and 0.40–0.50 m), treatments (control, nutrients, high organic matter plus nutrients; HOMN and very high organic matter plus nutrients; VHOMN), treatment applications (3), cycles (3) and measurement schedule (dots).

Results

Total organic carbon

Regardless of parent material or soil depth, there was no difference in total OC concentration between the control and nutrients only treatments, or within these treatments with incubation cycle. In contrast, adding OM and nutrients increased the concentration of total OC for both parent material ($P<0.001$) and soil depths ($P<0.05$). Total OC concentration increased with each HOMN and VHOMN treatment application. For example, in the basalt-derived 0–0.10 m soil, the VHOMN treatment increased total OC from 7.20% to 7.32%, 7.79% and 8.49% (0.5 se) in cycles one, two and three respectively. The increase in total OC was compared with the C added (Figure 2) and overall produced a linear trend. This increase was greater at depth ($P<0.001$) and was influenced by parent material ($P<0.05$). According to the C saturation concept, an asymptotic relationship (i.e. where the plotted line approaches, but does not reach a certain value) between OC concentration and C inputs indicates C saturation. However, regardless of initial OC concentration there was no asymptotic behaviour between C inputs and OC accumulation in soil observed in this study (Figure 2). Thus, OC accumulation was not approaching an upper limit at OM application rates ranging from 12.4 t DM/ha to 93.3 t DM/ha (equivalent to 5.4–40.6 t C/ha).

Interestingly, there was no significant increase in OC concentration between cycle two and three for the VHOMN treatment in the granite-derived 0.40–0.50 m soil and, while not conclusive; this might indicate that these soils may approach an upper limit to OC accumulation at a lower OC concentration due to the dominance of 1:1 clays.

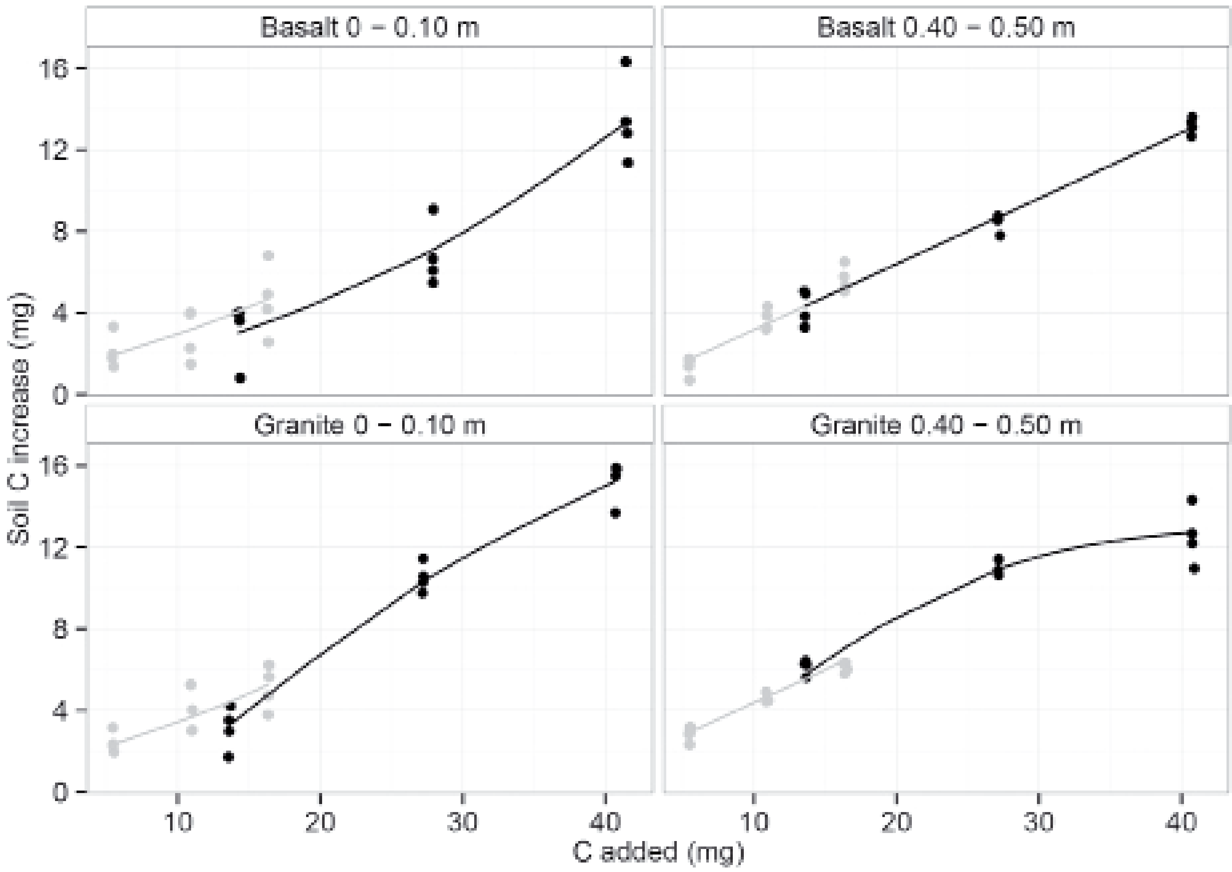

Figure 2. Relationship between the increase in soil C (mg/g; treatment less original C concentration) and the amount of C added (mg/g based on 43.51% C in OM) for basalt- and granite-derived 0–0.10 m and 0.40–0.50 m soil. Grey dots are the replicate values for cycles 1, 2 and 3 of the high organic matter plus nutrients (HOMN) treatment, and the grey line is the correlation. Black dots are the replicate values for cycles 1, 2 and 3 of the very high organic matter plus nutrients (VHOMN) treatment, and the black line is the correlation.

Nutrition & soil

Microbial biomass carbon (MBC) and ^{13}C recovery

The two microbial parameters used in this study were respiration (CO_2) and MBC. Microbial biomass carbon is composed of both metabolically active and dormant microorganisms, while CO_2 derives primarily from active organisms. The retention of the ^{13}C isotope throughout the three incubation cycles indicated the stability of accumulated OC. Despite increasing microbial activity, as evidenced by increasing soil respiration and MBC (Figure 3), as well as a significant ($P<0.05$) narrowing of the C:N ratio, there was substantial ^{13}C recovery at the end of the soil incubation. This indicates that the increases in OC accumulation were at least partly due to plant residues being converted into microbial detritus, which is a major component of the relatively stable pool of OC (i.e. humus) in soil. Furthermore, the mean recovery of ^{13}C in soil (between 19.8 and 25.9 (1.1 se) %) at the conclusion of the experiment is relatively consistent with the target of 30% efficiency in C retention from the applied OM on which the nutrient applications were based.

Summary

From the laboratory to the field…

These sites were under permanent pastures and literature indicates that such sites are close to C saturation, or have a small C saturation deficit. Despite this, the results from this laboratory study indicate that if OM and nutrient supply could be maintained at high levels, then these soils have the capacity to sequester more C. That is, at rates of up to 93.3 t DM/ha, no C saturation occurred.

However, we have presented a short-term (146 day) incubation experiment in a closed system. The issue of whether soil is approaching C saturation in the field or reaching equilibrium for that land use and management needs to be considered. To differentiate these in-field-based studies, climate and net primary productivity would need to be assessed. This would help to determine if constraints such as OM supply and decomposition, rather than inherent soil properties, were limiting OC accumulation in soil. Further, it is unlikely that current agricultural management in this environment could achieve such substantial increases in OM supply.

Regardless, our results support the theory that soil with a high OC concentration can continue to accumulate relatively stable OC where C and nutrient inputs are maintained. This biological OC stabilisation in soil needs to be considered to maximise the mitigation benefits of soil C sequestration in agricultural soil. Our study suggests a large potential for C sequestration in soils under permanent pastures in southern Australia, particularly as soil nutrition is something that can be managed.

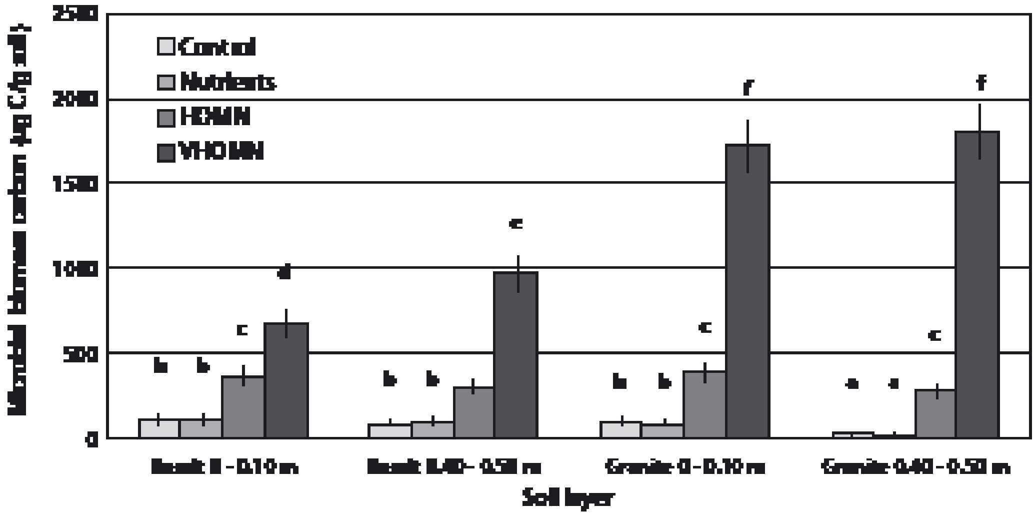

Figure 3. Microbial biomass carbon (µg C/g soil) at day 10 of cycle three for basalt- and granite-derived soil; 0–0.10 m and 0.40–0.50 m layers. Treatments include: control, nutrients, high organic matter plus nutrients (HOMN) and very high organic matter plus nutrients (VHOMN). Significant (*P*<0.05) differences indicated by different letters with testing completed using cube root data (5% l.s.d. was 1.01 on this scale). Error bars are approximate standard error as analysis was on the cube root scale.

References

Kirkby CA, Kirkegaard JA, Richardson AE, Wade LJ, Blanchard C, Batten G (2011). Stable soil organic matter: A comparison of C:N:P:S ratios in Australian and other world soils. *Geoderma* 163(3–4), 197-208.

Orgill SE, Condon JR, Conyers MK, Greene RSB, Morris SG, Murphy BW (2014). Sensitivity of soil carbon to management and environmental factors within Australian perennial pasture systems. *Geoderma* 214–215, 70-79.

Acknowledgements

This research was supported by joint investment by the Australian Government Department of Agriculture and Water Resources (National Soil Carbon Program) and NSW Department of Primary Industries. Claudia Keitel and Janani Vimalathithen (University of Sydney) are acknowledged for the stable isotope analysis and Albert Oates (NSW DPI) for the particle size analysis. The cooperation of the land holders in the Monaro regions whose properties were sampled is also acknowledged. This paper was part of a PhD thesis through Charles Sturt University and is published in the journal: *Geoderma* 285:151–163.