Soil carbon decomposition: effects of land use and mineralogy

Barry Thornton, Benjamin Butler and Nia Gray-Wannell

The James Hutton Institute, Craigiebuckler, Aberdeen, AB15 8QH, Scotland

Email: barry.thornton@hutton.ac.uk

HEALTHY SOILS FOR A GREEN RECOVERY

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Introduction

The changes in carbon isotope ratio $\delta^{13}C$ (‰) and carbon concentration (%) which occur going down the profiles of freely draining soils can be used to apply a Rayleigh equation determining ε, a proxy of soil carbon decomposition. The Rayleigh equation describes the isotopic fractionation which occurs on processing a single homogenous source material into a single product. Whilst in soil many carbon compounds are processed by microbes into multiple products, application of the equation has proved useful. For a soil profile the Rayleigh equation can be applied as:

$$\delta^{13}C_d = \delta^{13}C_t + \varepsilon\{\ln(C_d / C_t)\}$$

where $\delta^{13}C_t$ is the soil carbon $\delta^{13}C$ value at the top of the profile, $\delta^{13}C_d$ is the soil carbon $\delta^{13}C$ value at depth in the profile, C_t is the soil carbon concentration at the top of the profile, C_d is the soil carbon concentration at depth in the profile and ε is the Rayleigh enrichment factor. Plotting $\delta^{13}C_d$ against $\ln(C_d / C_t)$ at various depths allows ε to be determined from the gradient of the resultant curve. More negative ε values indicate greater soil carbon decomposition.

Methods

Sites of the National Soils Inventory of Scotland 2 (NSIS2) located at the intercept points of a 20km grid pattern across all Scotland were used. Of the 183 total sites, 64 were deemed unsuitable for calculating ε primarily due to waterlogging leaving 119 sites at which both $\delta^{13}C$ and carbon concentration (%) were determined using isotope ratio mass spectrometry down soil profiles allowing ε to be calculated. These sites were categorised into five differing land use types: arable, improved grassland, rough grassland, woodland, and moorland.

For the top horizon of both arable and improved grassland sites mineralogy was determined by X-ray powder diffraction (XRPD). As the mean XRPD patterns of the NSIS2 arable and improved grassland sites contained over 4000 variables, these were reduced using principal component analysis.

Additionally at 16 previously moorland sites but which had undergone afforestation for between 27 to 57 years, $\delta^{13}C$ and carbon concentration (%) were determined and ε calculated from samples taken both prior to and following afforestation.

Results

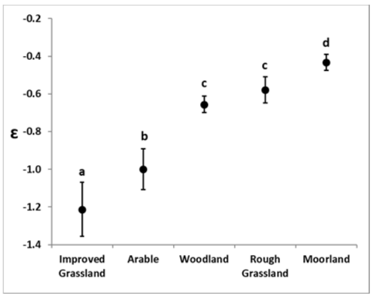

Figure 1: The ε values of differing land use types for the NSIS2 sites. Values are mean ± se, ε values sharing the same letter do not significantly differ from each other ($p > 0.05$). For improved grassland n = 26, arable n = 16, woodland n = 23, rough grassland n = 25 and moorland n = 29.

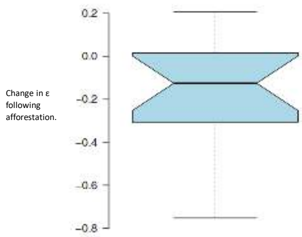

Figure 2: Box plot of the change in ε following the afforestation of previously moorland sites across Scotland. The whiskers represent the maximum and minimum values, the top and bottom edges of the box represent the first and third quartiles and the bold horizontal line within the box represents the medium value. The notches represent the 95 % confidence interval limits of the data, (n = 16).

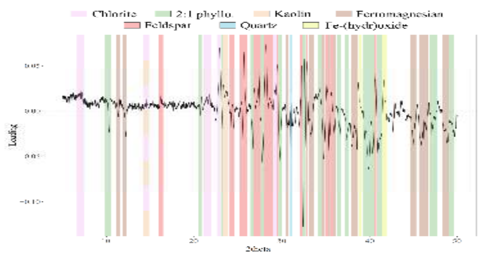

Figure 3: Loadings of PCA5 dimension (y axis) against the 2 theta (x axis). Upward pointing peaks, over zero on the y axis, indicate positive loadings where the mineral associated with those peaks increases with increasing ε and decreasing soil carbon decomposition. Similarly, downwards pointing troughs, less than zero on the y axis, indicate negative loadings where the associated mineral decreases with increasing ε and decreasing soil carbon decomposition.

At the NSIS2 sites, where land use types were spatially distinct, there was a clear effect of land use on ε (Fig 1). More negative ε values, greater decomposition, being associated with more fertile arable and improved grassland sites and less negative ε values, lesser decomposition, being associated with the less fertile rough grassland and moorland sites. These results suggest that the maximum benefit of mitigating climate change through reducing soil carbon decomposition by planting trees would occur on arable and improved grassland, land used for food production. They also suggest afforestation of moorland sites would increase soil carbon decomposition. The effects of afforestation on moorland was confirmed at previously moorland sites which had undergone afforestation, following afforestation the ε values of the sites became more negative indicating increased soil carbon decomposition (Fig 2).

Two PCA dimensions of the XRPD patterns, PC5 and PC11, showed significant ($p < 0.05$) relationship to ε. Multiple linear regression of ε as a function of PC5, PC11 and pH explained 51% of the variance whereas pH alone only explained 17% of the variance (data not shown). This suggests a role of soil mineralogy in determining ε and hence soil carbon decomposition in Scottish cultivated soils. On the PCA loadings of both PC5 (Fig 3) and PC11 (not shown), kaolin, chlorite, and feldspars had positive loadings, suggesting that increased amounts of these minerals in cultivated soils are associated with decreased soil carbon decomposition. Addition of kaolin was shown to decrease soil carbon decomposition in laboratory studies (Li et al, 2019, *Sci of Total Environ*,647: 570-576). Our work indicates this process operates under field conditions at a Scottish national scale.

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Conclusions

- Soil carbon decomposition is affected by land use, increasing in the order: moorland < rough grassland < woodland < arable < improved grassland.
- Afforestation of moorland sites resulted in increased soil carbon decomposition.
- Increased amounts of kaolin, chlorite and feldspar in Scottish cultivated soils are associated with decreased soil carbon decomposition at a Scottish national scale.