Climate exerts stronger control on topsoil carbon persistence than plant input in alpine grasslands

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Abstract

Chen et al. (2021) concluded that plant input governs topsoil carbon persistence in alpine grasslands. We demonstrated that the excluded direct effect of precipitation on topsoil Δ14C in their analysis was in fact significant and strong. Our results provide an alternative viewpoint on the drivers of soil carbon turnover.

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Statement of authorship

D.H.W. conceived of the comment and performed statistical analyses. D.H.W., X.T.X. and H.C.Z. drafted the manuscript.

Data accessibility statement

The data supporting the results of this study is downloaded from the supplementary material of Chen *et al.* (2021).

Abstract

Chen *et al.* (2021) concluded that plant input governs topsoil carbon persistence in alpine grasslands. We demonstrated that the excluded direct effect of precipitation on topsoil $\Delta^{14}C$ in their analysis was in fact significant and strong. Our results provide an alternative viewpoint on the drivers of soil carbon turnover.

Main text

Understanding the driving mechanisms of soil organic carbon (SOC) persistence is crucial to project future carbon-climate feedback (Schmidt *et al.* 2011). Chen *et al.* (2021) (*C21* hereafter) hypothesized that plant carbon input, as a proxy of priming effect, governs the topsoil carbon turnover across alpine grasslands in Tibetan Plateau. A structure equation model was built to assess the relationships between environmental variables and Δ^{14}C, an indicator of soil carbon turnover (Shi *et al.* 2020; Wu *et al.* 2021). However, only plant carbon input was considered as a direct effect on Δ^{14}C in their final optimized model while the direct climate effect was reported to be non-significant (**Fig. 3** in *C21*). From the model, plant carbon input exerts a stronger direct effect on topsoil carbon turnover, while precipitation only has a weaker indirect effect. The resultant lack of direct climate (mainly precipitation) effect on soil carbon turnover is surprising and contradictive to previous reports that soil carbon turnover is directly regulated by water availability especially in arid and semi-arid regions (Carvalhais *et al.* 2014; Wu *et al.* 2018).

We built and compared three possible structure equation models (**Fig. 1**) using the datasets provided in *C21* . Model-A only considered the direct effect of plant input on topsoil Δ^{14}C. By contrast, model-B included direct effects on topsoil Δ^{14}C from both plant input and precipitation. Model-C further included an additional direct effect from mineral protection. Model-A generated similar statistical results with *C21* , showing stronger total effect from plant input than from precipitation. In model-B, the two path coefficients related to Δ^{14}C from both plant input and precipitation are still significant ($P < 0.05$), and overall model performance (AIC = 19.945) is better than model-A (AIC = 21.989). Moreover, the strength of precipitation direct effect is comparable to that of plant input. As a result, the total standardized effect of precipitation is much larger than plant carbon input. In model-C, all three path coefficients related with Δ^{14}C fail to reject the null hypothesis based on significance level of 0.05 because of severe multicollinearity between the variables. Overall, the dataset in *C21* best supported model-B that includes direct climate effect. We could not include the chemical composition of soil organic matter, which nevertheless had no significant effects for topsoil in *C21* , in all the three models because the data was not made available.

We also conducted partial correlation analysis to detect the relative importance of direct effects from climate, plant input, and soil mineral composition on Δ^{14}C. Partial correlation analysis assesses the correlation between Δ^{14}C and one specific environmental factor after removing the effects of other environmental factors. The results showed that precipitation is still the most importance factor in regulating the topsoil carbon turnover than other factors (**Fig. 2**). Furthermore, we find precipitation governs the topsoil carbon turnover in alpine steppe, while temperature and mineral protection play major roles across alpine meadow. The difference likely implies that SOC decomposition is primarily limited by water in the drier alpine steppe, which is partially relieved in the wetter alpine meadow. In all cases, our results indicate that plant input does not play the dominant role in regulating the topsoil carbon turnover.

The overlook of direct climatic effects on SOC turnover can also bias the interpretation of the significant relationship between vegetation indices and topsoil Δ^{14}C on a global scale (**Fig. 4** in *C21*). *C21* interpreted these relationships as a universal law of the plant input effects on topsoil carbon turnover. However, the correlation can arise because preferable climatic conditions (e.g., warm and moist) increase both plant input and SOC decomposition rate (Davidson & Janssens 2006). Direct climatic effects on SOC turnover should be carefully removed before interpreting the plant input effects from these global data.

Aside from overestimating the direct effects of plant input on SOC turnover, *C21* treated the amount of plant input as a proxy of priming effects, which is however questionable. According to incubation experiments using soils from the same ecosystems by Chen *et al.*(2019), the amount of plant input does not show significant direct effect on soil priming intensity. Furthermore, components of plant input (shoot, root and mycorrhizal) usually have quite different effects in regulating priming effects (Huang *et al.* 2021). Therefore, it is unreasonable to simply use the amount of plant input as the indicator of priming effect.

Despite *C21* likely overestimated the contribution of plant input on SOC turnover, the study raised an important scientific question on the relation between SOC turnover and priming effect. Observed earth greening increased the fresh carbon input in soil system, which may promote the priming effects and accelerate the SOC turnover (Terrer *et al.* 2021). This crucial process is still missing in most existing ecosystem models (Wu *et al.* 2020), which may lead to an overestimation of the terrestrial soil carbon storage potential.

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Conflict of interest

The authors declare no conflict of interest.

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Figure legends

Figure 1 Three structure equation models (SEM) with different assumptions on direct and indirect relationships between environmental factors and topsoil Δ^{14}C are compared based on the available datasets for alpine grasslands provided by Chen *et al.* (2021). (a) Model-A includes direct effect of plant carbon input and indirect effect of precipitation on Δ^{14}C. (b) Model-B adds direct effect of precipitation on Δ^{14}C. (c) Model-C adds direct effect of precipitation and mineral protection and indirect effect of plant carbon input on Δ^{14}C. Fit indices, including degree of freedom (*DF*), Chi-squareis (χ^2), probability level (*P*), Akaike information criterion (*AIC*), comparative fit index (*CFI*), goodness of fit (*GFI*), root mean square residual (*RMR*) and root mean square error of approximation (*RMSEA*), are listed on the left panel of each model. Similar to Chen *et al.* (2021), precipitation is the first principal component (PC1) of mean annual precipitation (MAP), precipitation of the wettest month (PWM), and precipitation of the wettest quarter (PWQ); Plant C input is the PC1 of plant carbon input in topsoil, normalized difference vegetation index (NDVI), enhanced vegetation index (EVI) and leaf area index (LAI); mineral protection is the PC1 of molar ratios of dithionite- and oxalate-extractable Fe/Al oxides to SOC ($Fe_d + Al_d$ and $Fe_o + Al_o$), and the molar ratios of exchangeable Ca^{2+}(Ca_{exe}) and Mg^{2+}(Mg_{exe}) to SOC. Logarithm transformation is performed for the four variables of mineral protection before principal component analysis (PCA).

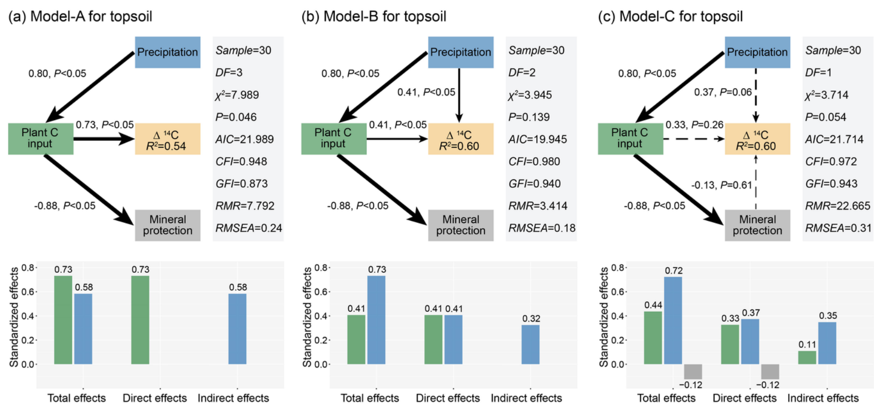

Figure 2 Partial correlations between topsoil $\Delta^{14}C$ and four environmental factors in alpine grasslands based the available datasets provided by Chen *et al.*(2021). The partial correlation between $\Delta^{14}C$ and each environmental factor is calculated by using the other three factors as the control variables. The partial correlation is also performed in alpine steppe and alpine meadow separately. Similar to Chen *et al.* (2021), precipitation is the first principal component (PC1) of mean annual precipitation (MAP), precipitation of the wettest month (PWM), and precipitation of the wettest quarter (PWQ); temperature is the PC1 of mean annual temperature (MAT), minimum temperature of the coldest month (MTCM) and mean temperature of the coldest quarter (TCQ); Plant C input is the PC1 of plant carbon input in topsoil, normalized difference vegetation index (NDVI), enhanced vegetation index (EVI) and leaf area index (LAI); mineral protection is the PC1 of molar ratios of dithionite- and oxalate-extractable Fe/Al oxides to SOC ($Fe_d + Al_d$ and $Fe_o + Al_o$), and the molar ratios of exchangeable Ca^{2+} (Ca_{exe}) and Mg^{2+} (Mg_{exe}) to SOC. Logarithm transformation is performed for the four variables of mineral protection before principal component analysis (PCA).