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Additive effects of litter and roots in forming soil organic carbon in forests

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Short Report

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Abstract

Plant input is an important source of soil organic carbon (SOC), but how and to what extent litter and roots interact to form SOC in various forests is not fully understood. Here, we compiled 189 paired observations from 23 studies to assess the changes in SOC concentrations after removing litter and living root inputs from different forests. We found that SOC concentrations reduced by 15.4% and 11.3% after litter and roots removal, respectively, but removing both litter and roots had an additive effect (24.8%), regardless of forest types. Our findings of the plant input removal experiments suggest that litter and roots had a similar but additive effect on forest SOC formation, although roots were more efficient than litter input. Thus, the study indicated that both efficiency and total amount of carbon input from aboveground and belowground biomass should be incorporated when evaluating the nexus between plant inputs and SOC formation.

Full Text

Plant inputs after decomposition not only directly participate in the soil organic carbon (SOC) pool, but also affect the SOC formation pathways by controlling microbial substrate utilization efficiency and microbial residues after biomass turnover (Wiesmeier et al., 2019; Dai et al. 2021); therefore, plant inputs are significance for terrestrial SOC formation. Both aboveground (leaves, twigs, branches, flowers, and fruits) and belowground (roots and their exudates) plant inputs return carbon and nutrients to soil in different quantities and quality different from the initial quality. Previous studies have shown that the litterfall in evergreen broadleaved forests is larger than that in coniferous forests, accounting for 37% and 25%, respectively, of the global litterfall (Shen et al., 2019). In addition, litter substrate quality (Ni et al., 2021) and carbon storage (Förster et al., 2021) also largely differs between forests. These diversities could affect microbial turnover rates and downstream SOC formation under plant input with different qualities.

Increasing number of studies have found that living roots play a significant role in the formation and stability of SOC in grasslands and croplands and that the contribution of living roots can be comparable to or even higher than that of litter input (Hu et al., 2016; Sokol et al., 2019). On the contrary, a recent meta-analysis found that root removal had a lower or equivalent effect on SOC than litter removal across global forests (Feng et al., 2022). However, whether litter and living root input interact to contribute to SOC formation across different forests and if they do, the extent of their interaction remains largely unclear. In this study, we hypothesized that: 1) litter and root input have an additive effect in contributing to SOC formation in forests, and 2) the magnitude of litter and root input effect on SOC is greater in broadleaved forests than in coniferous forests.

We retrieved 189 paired observations (with and without litter, living roots, and both litter and living roots) from 23 published papers via the Web of Science and China National Knowledge Infrastructure databases (further details provided in Supplemental Datasets S1 and Information S2). In this meta-analysis, we extracted the average values and standard deviations or standard errors of both control and

treatment (plant input removal) groups from each study to calculate the logarithm response ratio (ln *RR*) and 95% confidence interval using a random mixed effect model. We categorized the dataset at various levels of plant input types (litter, living roots, and both litter and living roots), experimental period (<1, 1–5, 5–10, and >10 years), and forest types (broadleaved vs. coniferous, deciduous vs. evergreen, and primary vs. plantation). The methods are presented comprehensively in Supplemental Information S2.

Litter and living root removal significantly decreased the SOC concentration by 15.4% and 11.3%, respectively (Fig 1a). The effect of litter removal was slightly greater than that of living root removal, but the difference was not significant ($P = 0.19$), which was consistent with the results of a recent study that used 32 paired observations (Feng et al., 2022) (Table 1). However, our results are in stark contrast to the previous results from grassland and cropland ecosystems (Kätterer et al., 2011; Hu et al., 2016), and this difference could be attributed to the method used and estimate bias from aboveground and belowground biomass inputs. Trenching (the most commonly used method in our study) allows root residuals to be left in the soils to partially offset the SOC loss induced by living root removal, and removing the litter alone can also affect root growth in the plots where roots were not removed (Feng et al., 2022). These uncertainties may underestimate the role of roots in SOC formation.

Contributions of aboveground and belowground plant inputs to SOC formation are closely related to both the efficiency and total amount of plant input (Villarino et al., 2021). Global belowground biomass accounts for 22% and 67% of the total biomass in forests and grasslands, respectively (Ma et al., 2021). Therefore, in forests, the aboveground biomass accounts for a greater (approximately 4 times higher) proportion of total plant biomass input, and thus, it is not surprising that the change in SOC concentration in response to litter removal observed in this study was slightly greater than that in response to root removal, although the difference was not statistically significant. Previous studies have not repudiated the efficiency of living roots in forming stable SOC (Sokol et al., 2019; Villarino et al., 2021). Contrastingly, our results from plant input removal experiments found no significant difference in the contributions of litter and living roots to SOC formation when considering more amount of litter input than that of root input (assumed as an average of 4:1). The acquired result only highlights the higher efficiency of living roots in contributing to SOC formation in forests.

The effect of living root removal on SOC concentration declined gradually after five years (Fig 1b), and this pattern differed from that of litter removal. Almost all the experiments excluded living roots by digging trenches and inserting plastic barriers around the plots (Table S1), but the severed roots were left in the plots. These roots could be decomposed naturally and utilized by microorganisms in the soils, although their decomposition rate is extremely slow (Sun et al., 2018). Studies have shown that it takes 9–54 years for the roots to be decomposed completely (Liu et al., 2017), while other studies have found that roots lost only 61–64% of their dry mass after eight years of decomposition (Wang et al., 2021). Therefore, the slowly decomposing roots in the soils contribute a consistent portion of carbon source, which may be one of the reasons why the effect of root removal on SOC decreased over time.

Litter removal showed a greater effect on SOC concentration in broadleaved than in coniferous forests (Fig 1c), partly resulting from the significant difference in litter C/N ratios. Litter quality strongly controls microbial substrate use efficiency (Cotrufo et al., 2013), and it is generally believed that the labile components in litter are much easier to be utilized by microorganisms (Bradford et al., 2013). Therefore, litter with lower C/N ratios decomposes quickly, with more labile compounds being released from decomposing litter materials, thus, increasing microbial substrate utilization efficiency and their metabolic products contributing to stable SOC in forests after microbial biomass turnover (Liang et al., 2017). By contrast, similar patterns were observed between deciduous versus evergreen forests and between primary forests versus plantations (Fig 1d, 1e), wherein, however, removing both litter and roots had additive effects on SOC concentration.

Statements & Declarations

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contributions

QW and XN proposed the ideas, analyzed the data and wrote the manuscript; FW conceived the ideas and provided in-depth suggestions for the manuscript; and, JZ, XW and JY helped collect the data. All authors gave final approval for publication.

Data Availability

The datasets supporting the conclusions of this article is included in the additional files.

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Tables

Table 1 The contributions of litter and root to SOC.

	Litter (%)	Root (%)	Method	Manipulation	Sample size
Present study	15.4	11.3	Indirect measurements	Removal	126 observations
Feng *et al.* (2022)	15.3	8.7	Indirect measurements	Removal	64 observations
Feng *et al.* (2022)	10.3	NA	Indirect measurements	Addition	57 observations
Villarino *et al.* (2021)	31	36	Isotopic tracing	Addition	197 observations

NA, not applicable.

Figures

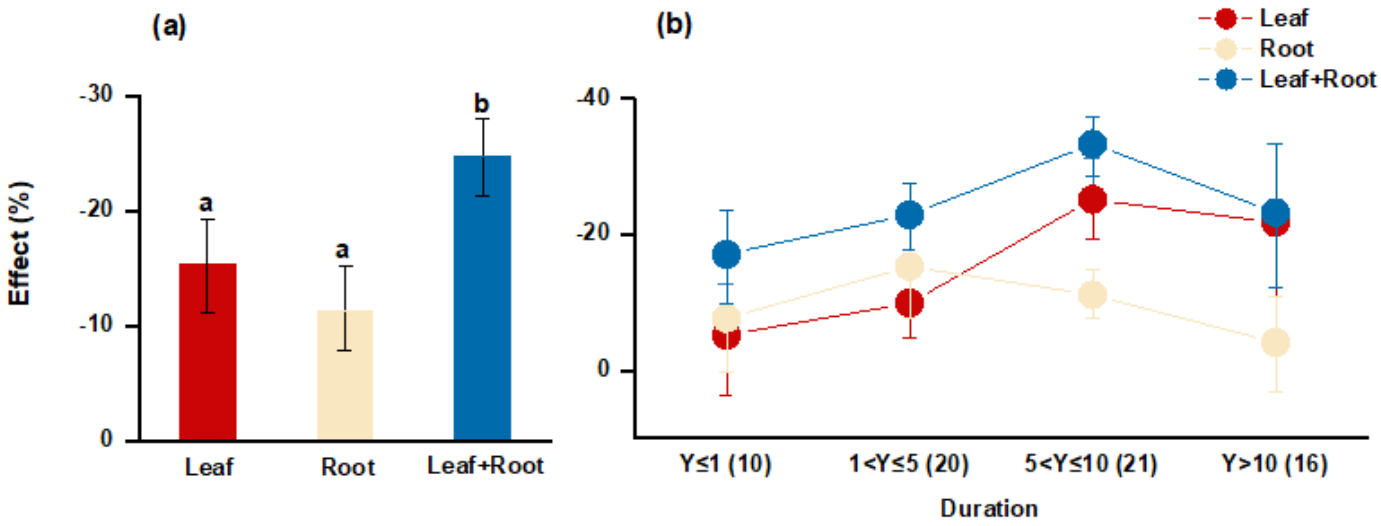


Figure 1

Percent change in soil organic carbon (SOC) concentration after plant input removal. (**a**) Average change in SOC concentration after removing litter, living roots, and both litter and living roots. Different lowercase letters denote significant differences ($P < 0.05$) among plant input types. (**b**) The effect of plant input removal on SOC concentration changed over time. Numbers in parentheses represent the sample size for each category. All values are shown as means ± 95% confidence intervals, and the effect of plant input removal was considered significant if the 95% confidence intervals did not overlap zero.

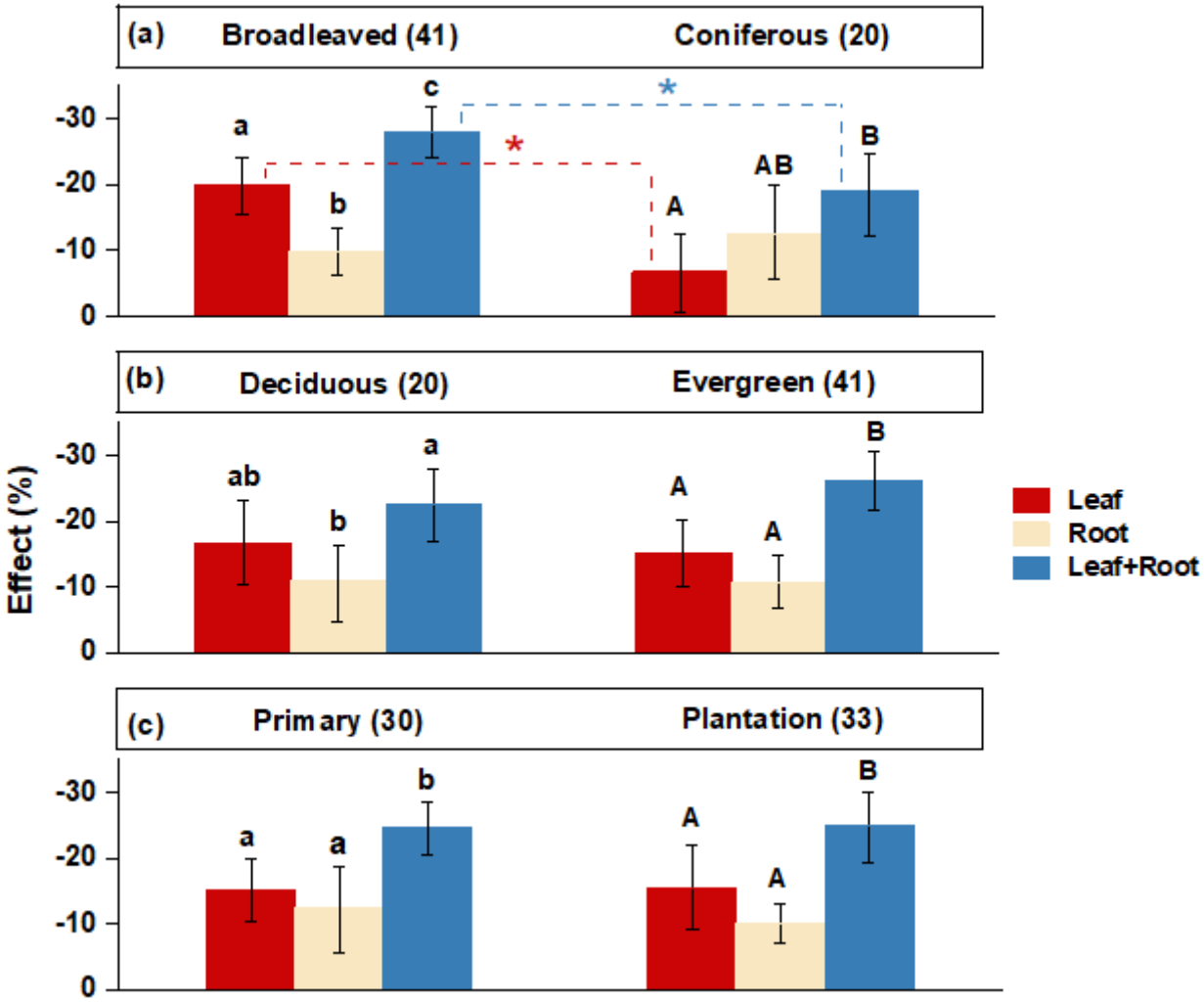


Figure 2

Percent change in soil organic carbon concentration after plant input removal in different forest types. (**a**) Broadleaved vs coniferous forests, (**b**) deciduous vs evergreen forests, and (**c**) primary forests vs plantations. The values are shown as means ± 95% confidence intervals, and the effect of plant input removal was considered significant if the 95% confidence intervals did not overlap zero. Asterisks denote significant (* $P < 0.05$) differences between forest types under the same plant input. Different lowercase (*left*) and uppercase (*right*) letters denote significant ($P < 0.05$) differences in SOC concentrations in response to plant input removal in a given forest.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementalDatasetsS1.xlsx
- SupplementalInformationS2.docx