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CALL FOR COLLABORATION

The TeaComposition initiative: Unleashing the power of international collaboration to understand litter decomposition

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Abstract

Collected harmonized data on global litter decomposition are of great relevance for scientists, policymakers, and for education of the next generation of researchers and environmental managers. Here we describe the TeaComposition initiative, a global and open research collaborative network to study organic matter decomposition in a standardized way allowing comparison of decomposition rate and carbon turnover across global and regional gradients of ecosystems, climate, soils etc. The TeaComposition initiative today involves 570 terrestrial and 300 aquatic ecosystems from nine biomes worldwide. Further, we describe how to get involved in the TeaComposition initiative by (a) implementing the standard protocol within your study site, (b) joining task forces in data analyses, syntheses and modelling efforts, (c) using collected data and samples for further analyses through joint projects, (d) using collected data for graduate seminars, and (e) strengthening synergies between biogeochemical research and a wide range of stakeholders. These collaborative efforts within/emerging from the TeaComposition initiative, thereby, will leverage our understanding on litter decomposition at the global scale and strengthen global collaborations essential for addressing grand scientific challenges in a rapidly changing world.

Keywords Litter decomposition | tea bags | harmonized data | TeaComposition initiative | networking networks

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Challenges in global studies

Ecosystems are under pressure from a multitude of stressors, most notably climate and land-use change (e.g., IPCC 2019, IPBES 2019). Prediction of system responses to these global change drivers are challenged by the extremely complex nature of ecosystems, the strong interlinkage of processes, the interactions among drivers and the interactions with natural or human-induced disturbances and management practices (e.g. Dietzen et al. 2019, Rillig et al. 2019). In recent decades, many studies have been conducted aiming to unravel these complexities through observations and experiments combined with modelling (e.g. Luo et al. 2011), and multiple studies and meta-analyses have aimed to synthesize and generalize our understanding across scales (e.g. Vicca et al. 2014, Song et al. 2019). Our general understanding of ecosystem processes and functions at the global scale is, however, challenged by the relatively small spatial scale and short-term nature of most studies, as well as by the lack of common methods and standards for conducting cross-site comparisons. This strongly limits our ability to synthesize studies globally and the capacity to adequately inform decision makers about the impacts of global change drivers on fundamental ecosystem processes.

Designing and implementing coordinated and low-cost field studies easily applicable at multiple sites across the globe is a way to integrate ecosystem research towards a common goal (Maestre & Eisenhauer 2019). In recent years, we have seen an increasing demand for coordinated observational and experimental ecosystem studies (Luo et al. 2011) and a plea for common methodologies, metrics and standards (e.g. Halbritter et al. 2020, Guerra et al. 2021). Global coordinated research networks (e.g. Luo et al. 2011, Mirtl et al. 2018), are already providing unique insights and generalities regarding ecosystem functioning and responses to global change drivers (e.g. Maestre et al. 2012, Delgado-Baquerizo et al. 2013, Borer et al. 2020), and hold great promise to advance our understanding of planetary responses to such drivers.

Leaf litter decomposition

Decomposition of organic matter is a fundamental process in ecosystems, releasing CO_2 and CH_4 from decaying organic materials back to the atmosphere and transferring carbon and nutrients from the biosphere to the soil and aquatic ecosystems (Berg & McClaugherty 2020). Plant litter decomposition is regulated by a complex interplay of factors, including the composition and activity of soil biota, abiotic conditions (e.g. moisture, temperature, oxygen availability), plant diversity, and the intrinsic chemical composition of litter materials (e.g. Berg & McClaugherty 2020). Plant litter decomposition, therefore, plays a significant role in the feedback between the biosphere and the atmosphere (e.g. Van Groenigen et al. 2014), but at the same time, we still face major unknowns in our general understanding of this process such as the controls on carbon stability and atmospheric feedback.

Litter decomposition can be studied by direct *in-situ* respiration measurements of soil respiration (Singh & Gupta 1997). Such studies provide in-depth process-based data, linking short-term dynamics and controlling drivers, but they are costly and upscaling is significantly challenging because of the small spatial (plot) and temporal (few years) scales of the measurements (Moore et al. 2017). Alternatively, litter decomposition can be studied by direct incubation of litter in the field and subsequent measurement of the carbon (and nutrient) loss over time. Such studies provide very useful integrated measures of decomposition, with incubation periods spanning from months to 10 years (e.g. Long-term Intersite Decomposition Experiment (LIDET), the Canadian Intersite Decomposition Experiment (CIDET). However, these are most often conducted based on site specific litters, and methodologies and comparison of similar data across different experiments and sites still poses a major challenge due to the lack of common protocols and standard matrices. To overcome these limitations, the Tea Bag Index (TBI) method has been developed (Keuskamp et al. 2013). This approach is based on the *in-situ* incubation of two types of tea: Rooibos tea characterized by a slow decomposition rate and Green tea characterized by a higher decomposition rate. The advantage of this approach is that commercially available tea bags constitute a pre-made 'litterbag'. Hence, any variation related to user differences in preparation and associated workload are marginal. In addition, tea bags are filled with the tea leaves and resemble thus more natural litter than the commonly used cotton strips (Tiegs et al. 2007). Limitation of the tea bags is primarily related to the mesh size (0.25) that excludes the larger soil fauna (Bradford et al. 2002), which are of significant importance in most environments (Eggleton et al. 2020). In the TBI approach the litter bags are incubated for 90 days, and thus it provides valuable insights into short-term dynamics of plant litter decomposition (Ogden 2017, Spiegel et al. 2018). Yet, extrapolating from short-term to long-term decomposition rates is still challenging due to the fact that the quality of litter changes with progressing decomposition and therewith it's controlling factors (Moore et al. 2017). Repeated observations over time, such as those proposed by the TeaComposition initiative we describe below, are thus essential for improving our understanding of temporal dynamics of the decay process of plant litter.

The **TeaComposition initiative** is a global and collaborative litter decomposition study aiming to estimate short- to long-term plant litter decomposition rates by using standard protocols and litter materials (Fig. 1A). The standardized protocol ensures: (i) use of the same batch of tea bags assuring the same substrate quality for all sites, (ii) harmonized start of the decomposition at the same season at the year for northern and southern hemisphere, (iii) comparable incubation depth at the upper 5 cm of the soil relevant for litter decomposition, and (iv) standardized incubation times with the sampling points after 3, 12, 24, and 36 months.

TeaComposition is being successfully developed across nine biomes, including 570 terrestrial and 300 aquatic sites worldwide (Fig. 1B, C). More than >80,000 tea bags have been deployed by volunteers from academia, government bodies, scientific institutes, and citizen scientists through an online coordinated effort. The results comparing the early stage of decomposition after three months of incubation have demonstrated the strong potential of the approach (Djukic et al. 2018), and further research is ongoing in capturing the long-term dynamics and in analyzing the role of soil biodiversity, environmental factors, and litter chemistry in further depth.

The value and importance of comparable and feasible methods to inform about decomposition and carbon turnover related to climate and global changes is clear from the involvement in TeaComposition of multiple experimental and global research networks such as TreeDivNet (https://treedivnet.ugent.be/), TERENO (https://www.tereno.net/), DIRT (https://dirtnet.wordpress.com/), ILTER (https://www.ilter.network/), GLORIA (https://gloria.ac.at/home) and INTERACT

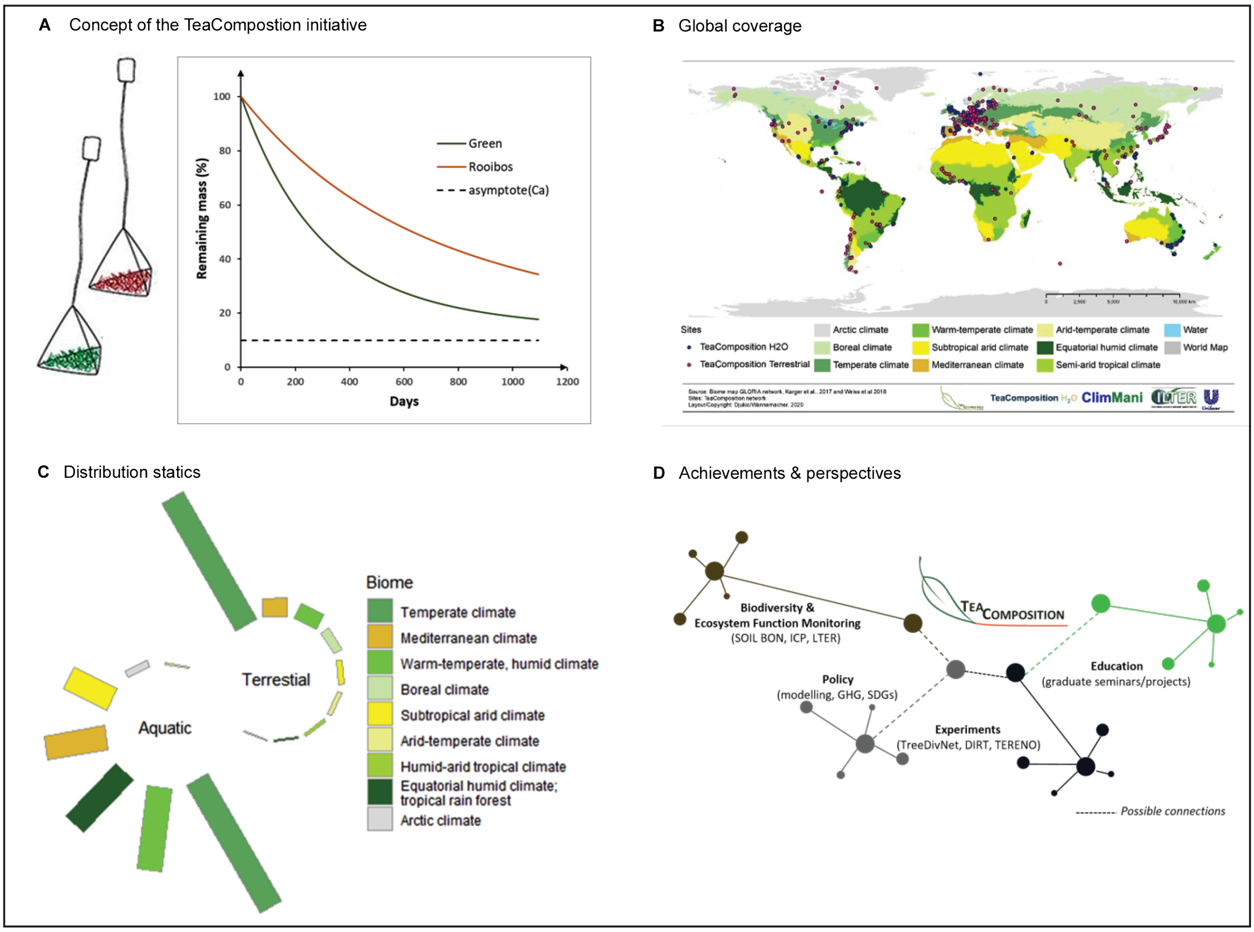

Figure 1. TeaComposition initiative. (**A**) An illustration to the asymptotic model (cf Berg 2014) for decomposition of standard tea bags (0.25mm mesh) of Green (*Camelia sinensis*) and Rooibos (*Asphalantus linearis*) tea, representing litter decomposition (here as mass remaining) over a period of three years. Dashed horizontal line shows the limit value (stabilized residue); (**B**) site distribution in terrestrial (red dots) and aquatic (blue dots) ecosystems across nine world biomes in 2020; (**C**) Number of participating sites per biome; (**D**) Networking activities of the initiative include active and potential collaborations with the following global research networks: Soil Biodiversity Observation Network (SoilBON), International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects (ICP), Greenhouse gas inventory (GHG), Sustainable Development Goals (SDGs), Tree Diversity Network (TreeDivNet), Detrital Input and Removal Treatments (DIRT), and Terrestrial Environmental Observatories (TERENO).

(https://eu-interact.org/). Such global implementations make the quantification of litter carbon turnover possible at a high resolution, both temporally and spatially, capitalizing on local data to elucidate the abiotic and biotic drivers of decomposition processes. TeaComposition hereby plays an important and inclusive role linking different networks of terrestrial ecological studies. In recent years, the TeaComposition initiative has expanded to also include aquatic ecosystems in the framework of the '**TeaComposition H_2O**' initiative (https://www.bluecarbonlab.org/teacomposition-h2o/). Together, these TeaComposition initiatives provide a unique platform and common metric-important for crosscutting conceptual ecological comparison and understanding of the abiotic (e.g., temperature, precipitation, elevation) and biotic (microbial activity, litter quality) factors involved in the control global litter carbon turnover.

Data handling and policy is following the FAIR principles (Wilkinson et al. 2016). Data on litter decomposition and ancillary environmental data collected at the sites or gathered from existing global databases will be stored in a dynamic data repository. The data will be made available as data descriptors following the publication of scientific articles according to the milestones of the initiative, thus providing full accessibility to external users. Similarly, metadata of collected samples will be freely accessible within the TeaComposition sample catalogue (Catalogue of samples - http://get-it.it/objects/samples/TeaBag/_site/index.html; Oggioni & Bergami 2021).

The data allow not only global cross-site comparison and large-scale trend analyses, but also the comparison of locally collected data with global, freely accessible datasets from the TeaComposition initiative. Further, data from the TeaComposition initiative have the potential to be used for teaching purposes in schools as has already been done for graduate seminars (e.g. Phyton course at Columbia University) or to extend research questions (Aguilar-Cruz et al. 2020). If you wish to use data or samples, a storyline should be submitted to the corresponding author for a general review.

Perspectives

Policy support & addressing data gaps

Leaf litter decomposition is of significant relevance for developing forecasts on soil carbon and nitrogen dynamics and stocks under different climate, land-use, and policy scenarios (Fig. 1D). The TeaComposition initiative provides a unique opportunity to collect harmonized and comparable data of different climatic zones, land-use types, drivers, and management practices at all scales for informing and calibrating carbon models. This is essential for the up-scaling of consequences of environmental changes for ecosystem functioning, carbon storage capacity and contribution to greenhouse gas (GHG) emissions, relevant for national GHG inventories and IPCC reporting. The tea bag approach, however, provides information about the potential decomposition rates in a given ecosystem. In order to provide a link between the potential (i.e. based on standardized tea litter) and actual (i.e. based on local litter) decomposition rates, simultaneous incubation or data of native litter would be needed (Didion et al. 2016). In addition, information on the role of soil fauna in decomposition process is required in order to provide true unbiased results for global understanding of litter decomposition rates and their impact on carbon and nutrient cycling (García-Palacios et al. 2013, Eggleton et al. 2020). Therefore, further efforts to harmonize and apply worldwide a complementary method that includes larger fauna are important and we would welcome collaborations with the partners collecting data on the litter decomposing biota.

Globally, environmental data are latitudinally skewed with more studies in the Northern than Southern Hemisphere (e.g. Guerra et al. 2020), due to regional differences in research effort and investment (Maestre & Eisenhauer 2019). This will potentially result in a biased process understanding since ecological processes and their underlying drivers are highly ecosystem-dependent. Applying cost-effective methodologies using standardized protocols across sites such as the TeaComposition initiative therefore provides a means to overcome such data gaps, and contribute to improving ecological literacy for ecosystem research and environmental policy formation (Maestre & Eisenhauer 2019). The TeaComposition initiative particularly encourages institutions, communities, or individuals from underrepresented areas to participate (Fig. 1C). Interested collaborators are asked to express their interest by contacting the corresponding author. The amount of work for each site is restricted to installation and collection of the tea bags (corresponds to 10 workdays over the period of three years). Anyone who contributes data will be offered co-authorship for the core papers of the initiative.

Networking Networks

Effects of global change on ecosystems will occur across large spatial scales, and new meta-networks will be instrumental for data and analytical sharing beyond site-based research (e.g. Rastetter et al. 2011, Maestre & Eisenhauer 2019). The TeaComposition initiative has established collaboration among multiple networks, teams, and researchers working in multiple fields, such as add-on studies focusing on soil microbial biomass and diversity, aggregate stability, nutrient availability assessments, and soil microbial diversity (Heintz-Buschart et al. 2020, Guerra et al. 2021) (Fig. 1D). By doing so, the TeaComposition initiative aims to become a unique source for standardized cross-site procedures and information and an example of a comprehensive overview of existing research activities, reducing duplication of efforts and closing data gaps thereby (Fig. 1D). As an inclusive network, TeaComposition works to support the sustainable development goals, which requires significant cross-disciplinary and collaborative networks across many research fields and directions. Therefore, we encourage colleagues, scientists as well as non-scientists, worldwide to join TeaComposition and/or to propose further collaborative research within other fields to unleash the power of scientific collaboration to tackle grand scientific challenges (e.g. carbon feedbacks in the climate systems, factors affecting biological diversity and ecosystem functioning).

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